(12)

NOSC

NOSC TR 483

LEVEL II

NOSC TR 483

Technical Report 483

HYDRAULIC COMPONENT ACOUSTIC COMPATIBILITY STUDY

MS Shimamoto

October 1979

Final Report: 1972 — 1975

Approved for public release; distribution unlimited

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA 92152

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

SL GUILLE, CAPT, USN
Commander

HL BLOOD
Technical Director

ADMINISTRATIVE INFORMATION

The work reported here was conducted under the NAVORD 6.2 Deep Recovery System (DRS) program, task number 00000-3-65025. Testing was performed during the period 1972–1975.

Released by
JK Katayama, Head
Ocean Systems Division

Under Authority of
JD Hightower, Head
Environmental Sciences Department

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER NOSC Technical Report 483 (TR 483)	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) HYDRAULIC COMPONENT ACOUSTIC COMPATIBILITY STUDY,		5. TYPE OF REPORT & PERIOD COVERED Final 1972–1975
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) MS SHIMAMOTO		8. CONTRACT OR GRANT NUMBER(s) (14) NOSC/TR-483
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Ocean Systems Center, Hawaii Laboratory PO Box 997 Kailua, Hawaii 96734		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NAVORD 6.2 DRS Task Number 00000-3-65025
11. CONTROLLING OFFICE NAME AND ADDRESS (12) 101	(11)	12. REPORT DATE Oct[redacted]979
		13. NUMBER OF PAGES 99
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(9) Final rept, 1972 - 1975

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Acoustic, Compatibility, Hydraulic, Motors, Noise, Pumps, Relief valves, Servo valves

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Remote Unmanned Work System (RUWS) is a cable-tethered, unmanned work vehicle capable of performing deep ocean search, inspection and work tasks to depths of 20,000 feet. The vehicle and primary cable termination are open frame structures, thus, hydraulic components are located directly in seawater. Since the submersibles generally require simultaneous use of their propulsive capability and acoustic sensors such as sonar, the acoustic noise of the equipment must be low so that performance of the acoustic sensors is not degraded. This document reports the investigation of acoustic noise outputs of off-the-shelf hydraulic components for use aboard RUWS.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

393159

CONTENTS

ILLUSTRATIONS

TABLE

INTRODUCTION

Deep ocean submersibles often employ an open frame construction which necessitates locating hydraulic components directly in seawater. The noise produced by the hydraulic components is therefore directly transmitted to the water. The submersibles generally require simultaneous use of their propulsive capability and acoustic sensing in carrying out their missions. Remote Unmanned Work System (RUWS) operations, for example, require that a variety of variable-speed mechanical functions be performed during the mission; thrusters will be in continuous operation on both the vehicle and primary cable termination (PCT). Since all of the sonar systems will be operating during the same period, the acoustic noise of the RUWS equipment must be sufficiently low that the performance of the acoustic sensors is not degraded.

An investigation was performed under the Deep Recovery Systems Program during 1972-1975 to evaluate the acoustic noise outputs of off-the-shelf hydraulic components. For the purposes of this test series the acoustic compatibility requirements used were those for the RUWS. The objective was to test available components and select those with acceptable acoustic outputs for use in the RUWS hydraulic system. The components were evaluated under conditions that would be seen in the RUWS system, i.e., a 1000-psig system with a pressure compensated reservoir. Four types of components were acoustically tested and compared: motors, pumps, relief valves, and servo valves.

Tests were run with atmospheric return line pressure and elevated return line pressure to simulate the effect of increased ambient pressure on the noise output of the components when they are compensated to the higher ambient pressures at depth. This was done by increasing the return line pressure while maintaining a 1000-psi differential pressure. Hydraulic noise output may be significantly reduced by back-pressuring the components above 450 psi. This high pressure eliminates cavitation and its attendant noise in the components, indicating that a hydraulic system, pressure compensated to ambient pressure, will be much quieter at depths below 1000 feet, where the pressure is approximately 450 psi.

Graphs of the recorded acoustic signatures are shown in the appendices.

BACKGROUND

The RUWS, illustrated conceptually in figure 1, is designed to perform a variety of engineering and scientific tasks at ocean depths of 6,100 metres (20,000 feet). It is a major element of the Navy's Deep Ocean Technology (DOT) project. RUWS provides coverage of more than 98 percent of the ocean floor.

To accomplish a wide variety of missions (such as recovery, repair, emplantment, survey, documentation, and gathering of oceanographic data), a modular design approach has been taken. The RUWS work suit consists of a manipulator pair with interchangeable tools (e.g., drilling and cable cutting). The work suit simulates man's presence in the remote vehicle to achieve maximum versatility in its operation.

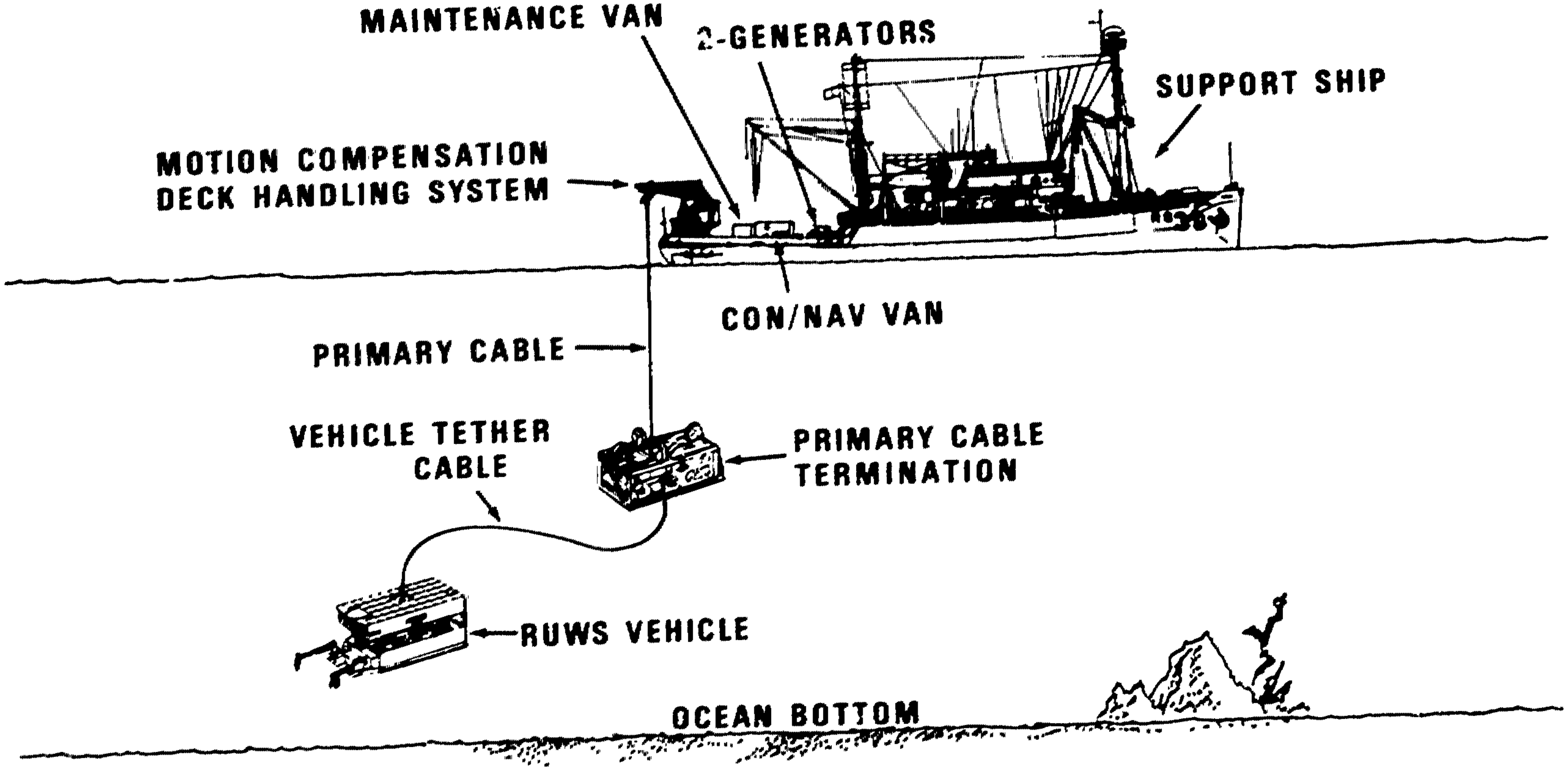


Figure 1. The Remote Unmanned Work System (RUWS).

The electromechanical tether cable for RUWS employs a Kevlar strength member and single coaxial electrical member. Power and command/control signals to the vehicle and the wide bandwidth video and sensor data from the vehicle are simultaneously transmitted on the tether cable through use of time and frequency multiplexing techniques.

Hydraulically-powered systems wer- selected to perform the RUWS mechanical functions because of their tolerance to high ambient pressures and their inherent versatility through simple variable-speed controls. Hydraulic systems are compact and offer a low weight-to-power ratio. Weight is significant because of the high cost of syntactic foam that is needed to provide vehicle buoyancy at depths to 6,100 metres (9,000 psi).

Another majoi factor for selecting electrohydraulic propulsion systems over electric propulsion systems was that controllable electric drive motors would cause a varying electrical load which would produce large line voltage variations at the vehicle due to the IR (current X cable resistance) loss in the cable. The RUWS system uses a 8,315-metre (24,000-foot) coaxial electromechanical cable that transmits up to 45 kVA of 60-Hz. 3000-volt power to the PCT and vehicle. The electrical control and information signals are time-division multiplexed onto the coaxial power cable. The sensitivity of the multiplexing circuitry requires a fairly constant voltage level. Large voltage regulators with their attendant high heat load would be required for large line voltage variations. By operating a fixed-displacement hydraulic pump at a constant speed and throttling excess oil flow through a relief valve the electric pump-drive motor is under constant load, thereby minimizing the electrical current variation.

Hydraulic propulsion systems, however, tend to produce more noise than electric propulsion systems. Components in a hydraulic system considered to be major noise producers are pumps, motors and valves.

The objective of this program was to select several commercially available hydraulic pumps, motors and valves as condidate components for the RUWS electrohydraulic propulsion system, perform acoustic tests on the components, and select the quietest components that would fit the requirements for the RUWS hydraulic system.

SYSTEM OPERATING REQUIREMENTS

The components in RUWS submersibles requiring electrohydraulic power consist of the thruster drives, vehicle tether winch and traction drives, and the vehicle's work suit (manipulators, camera gimbal, and special tool drives). Figure 2 depicts the RUWS vehicle, its thrusters and work suit. The thruster arrangement provides four degrees of propulsive control: vertical, transverse, fore and aft, and yaw.

The vehicle work suit (reference 1) consists of a seven-function manipulator, a four-function grabber, a TV-camera pan and tilt gimbal, and various work tools. The work suit is electronically controlled and hydraulically powered. To meet the design performance goals for the work suit, 1000 psi was needed for the hydraulic supply pressure, and therefore 1000 psi was selected for the RUWS vehicle system pressure. Candidate hydraulic components selected for use on the vehicle were tested at 1000-psi differential pressure for the acoustic compatibility evaluation.

1. Marrone, R. A., J. Held, and R. W. Uhrich, "Manipulator, Grabber and Tools for the RUWS Work Subsystem", NUC TN 818, Volume 2, November 1972.

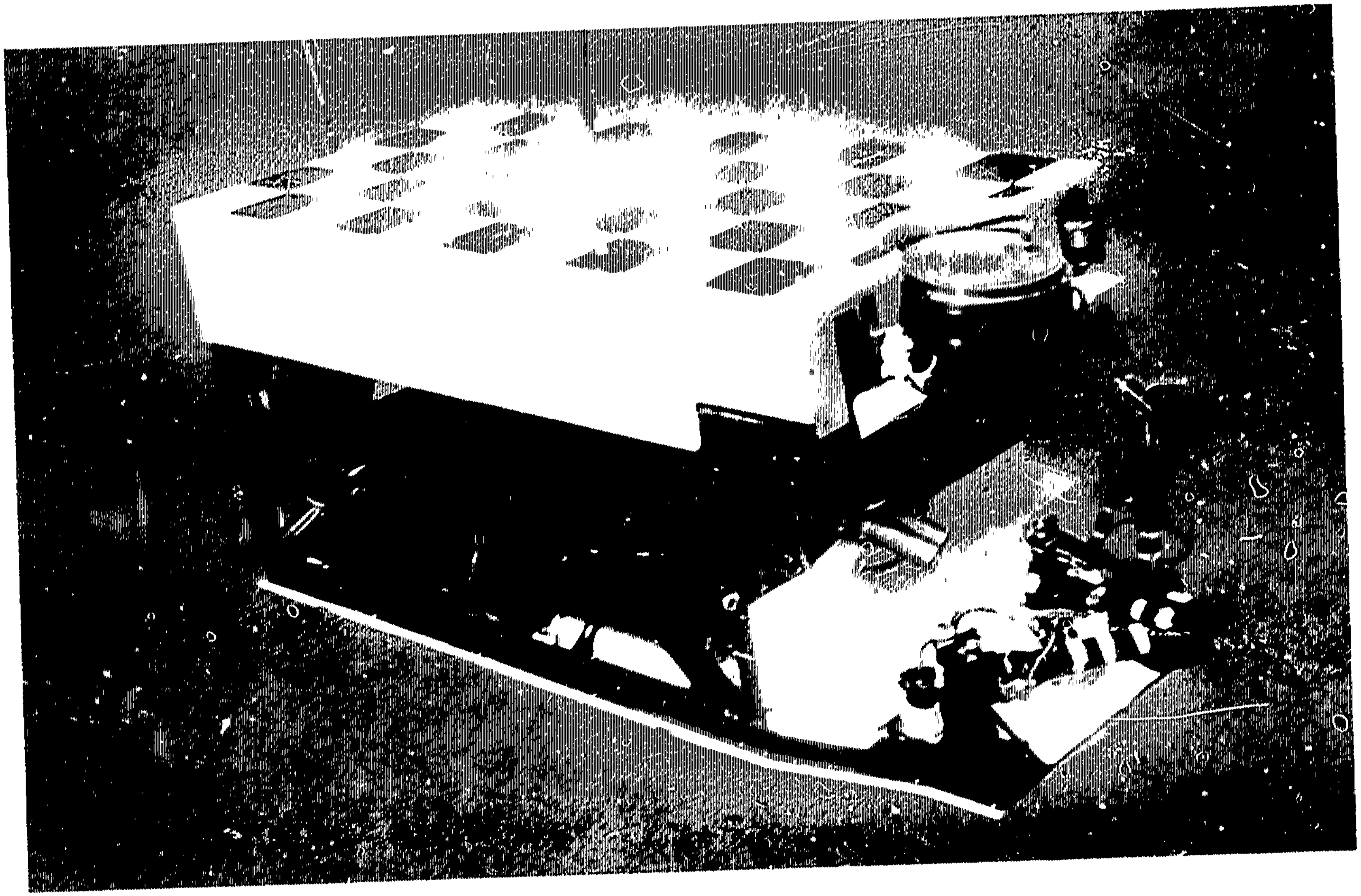


Figure [illegible]. The PFWS vehicle

ACOUSTIC COMPATIBILITY CRITERIA

Prior to selecting components for the power system it is necessary to establish the operating ranges for the submersible system's acoustic sensors. The acoustic frequency bands for the RUWS search and navigation systems are shown in figure 3 (references 2 and 3). To achieve acoustic compatibility, the acoustic output of the hydraulic components must be minimized in the operating bands of the various RUWS acoustic sensors.

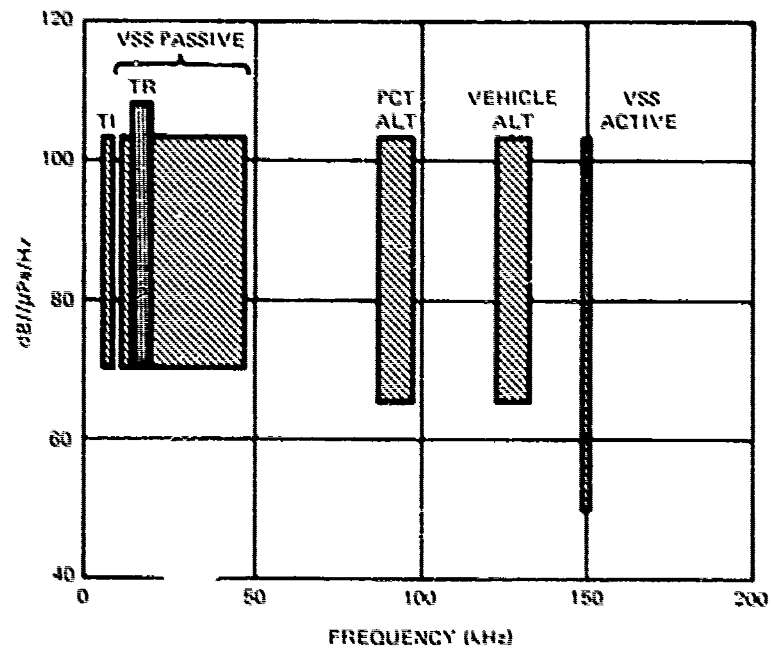


Figure 3. RUWS acoustic frequency spectrum.

2. Volberg, H. W., "Specifications for Vehicle Search Sonar (VSS) Equipment", NUC Hawaii Laboratory, Code 6531, December 1971.
3. Volberg, H. W., "Specification for Long Range Tracking Sonar (LRTS) and Altimeter Equipment for the Remote Unmanned Work System", NUC Hawaii Laboratory, Code 6531, February 1972.

COMPONENT SELECTION

The hydraulic power and propulsion system used on RUWS is shown schematically in figure 4; the schematic is simplified to show only one propulsion motor and one typical actuator. The system is typical of most hydraulic systems consisting of a prime mover, pump, relief valve, proportional control valves, motors, hydraulic cylinders and a heat exchanger.

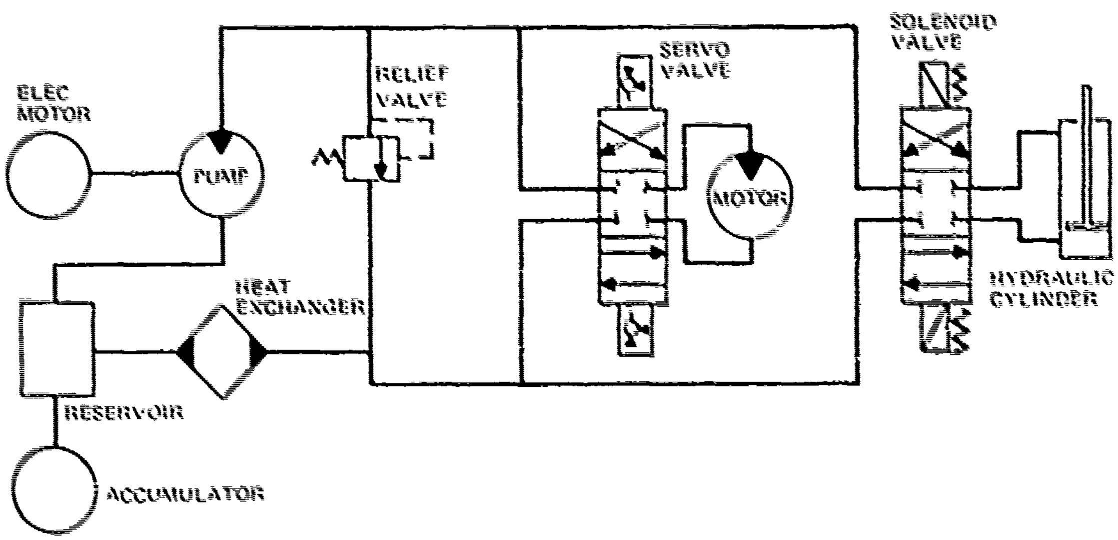


Figure 4. RUWS simplified hydraulic schematic.

The RUWS hydraulic system reservoir has a spring-loaded accumulator that maintains reservoir pressure at 5 to 10 psi above ambient while compensating for the reduction in oil volume due to the high ambient pressure and low ambient temperature at depth. Therefore, the pump output is always 1000 psi above ambient pressure.

A variety of commercial hydraulic components were selected as being operationally suitable for use in the RUWS hydraulic system. These components were tested underwater with acoustic instrumentation to determine their waterborne acoustic profile under simulated RUWS operating conditions. The following components have been tested.

Electric Motors	General Electric, Model 4K254A K205 Louis Allis Pacemaker Motor
Pumps	Borg Warner, Model P4-2B DeLaval, Model IMO A12-DB-137 Vickers, Model V30-1F15F-1CL Racine Supervane Hydrastar, Model 5-HI-20G
Motors	WSI, Model 35 Mark VI* Nutron, Model MF AV-2.5 Char-Lynn, Orbit Model AAS* Lamina, Model A-62F* Planet, Model MV-.93-A1A2B1A1*
Servo Valves	Olsen, Model S-5C Moog, Model 74-104 Moog, Model 35-A-76-15-E-05-6-A 4 Sanders, Model SV-438-10P
Relief Valves	Republic, Model RG70-2-3/4 S2-1/4 Vickers, Model CT-10-C-20 Fluid Controls, Model 1AR41-F10-30S Fluid Controls, Model 1A32-R6-30S Circle Seal, Model P10-776 Rolamite, designed and fabricated at NOSC

*Tested at Ku Tree Reservoir

The electric motors were necessary for test purposes to drive the pumps. Their noise outputs were very low and did not significantly contribute to the results of the pump tests (graphs A-101 and A-102 in appendix A).

COMPONENT EVALUATION

The facilities and procedures used in evaluating the candidate components are described in the following paragraphs.

TEST FACILITIES

The initial tests were conducted at Ku Tree Reservoir (figure 5) in central Oahu. This site was desirable because of its large water volume and its bottom profile, which minimized reverberation at the hydrophone. Because of logistics problems encountered at that remote test site, however, the tests were continued in a Doughboy swimming pool, 28 feet in diameter by 4 feet deep (figure 6). The reverberation off the walls and bottom of the pool produced an

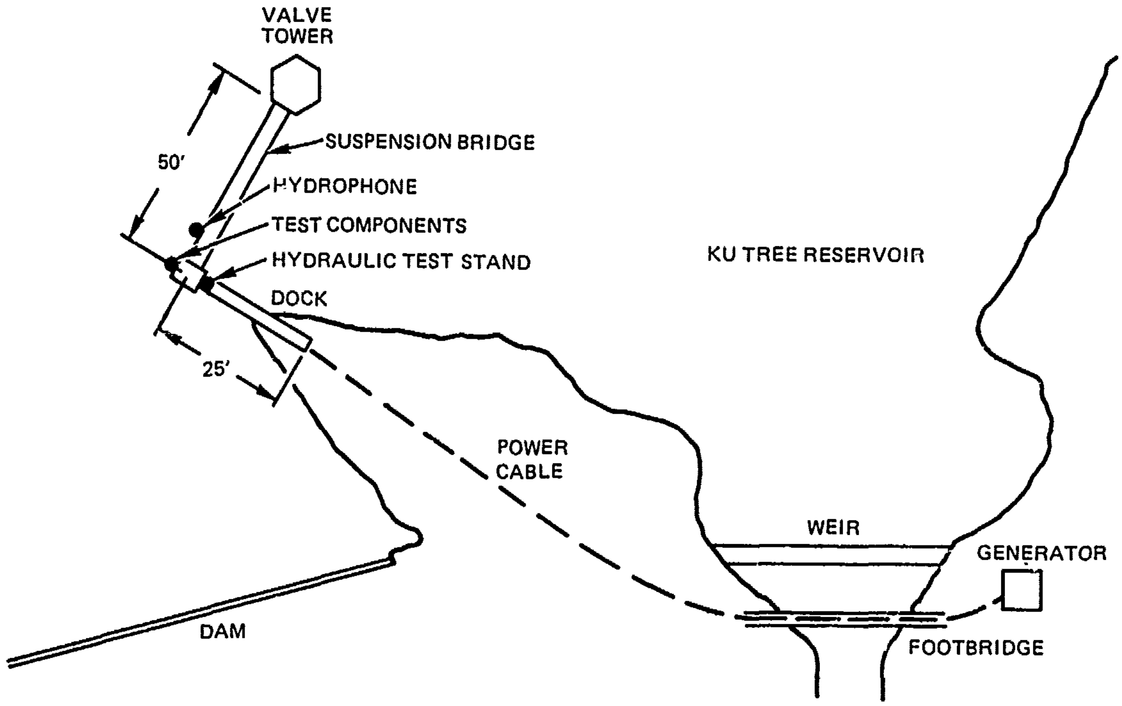


Figure 5. Ku Tree Reservoir test layout.

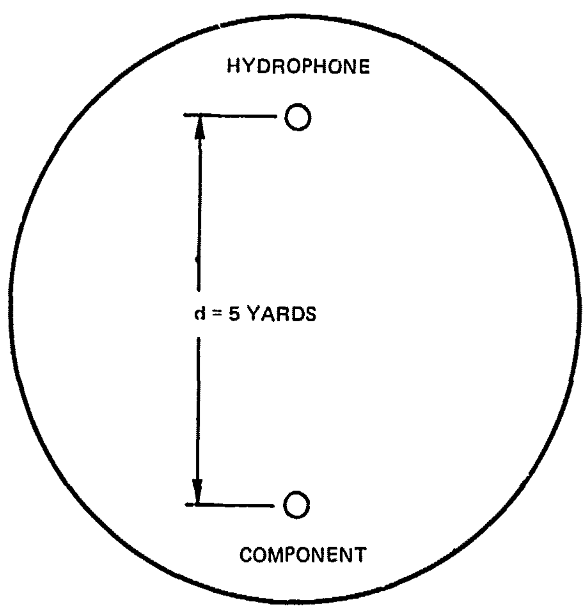


Figure 6. Doughboy swimming pool test layout.

increase in the measured sound pressure levels, but the shapes of the noise spectrum approximated those recorded for the same component tests at the reservoir (figure 7). It was observed that the sound pressure curve shift was in proportion to the absolute noise level; i.e., the increase in sound pressure level was largest for the noisiest components and less for the quieter ones. In all cases, pool readings were higher than open water readings, so the use of pool noise readings for component selection is felt to be on the conservative side.

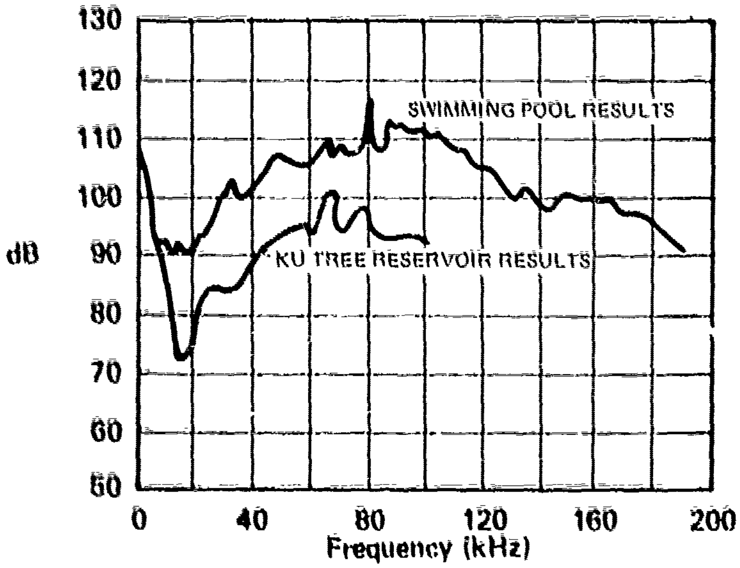


Figure 7. Acoustic tests on Moog 74 servo valve comparing swimming pool result with Ku Tree Reservoir result.

In 1973 a saltwater test pool was built at the NOSC Hawaii Laboratory and was then used for further acoustic testing. Figure 8 illustrates the layout of the saltwater test pool. Table 1 shows which components were tested at which facility. Only those components tested in the same facility should be compared.

The components and hydrophone were suspended from cantilevered beams and submerged half-way to the bottom of the pool. No hoses or brackets touched the sides or bottom of the pool.

A hydraulic test stand was used to supply pressure and flow to the motors and valves for testing. The test stand was equipped with pressure gages to monitor output and return pressures, a flowmeter to monitor flow to the components, and valves to control output and return pressures and flows. Hydraulic oil, MIL-H-5606, was used in the tests.

SOUND MEASUREMENT EQUIPMENT

Acoustic measurements were made using a Clevite Hydrophone, Model CS-331AAG (KMY), which consists of a CH-3A sensor and a CA-31AG preamplifier assembly. This system was calibrated by Clevite and had a flat response of -66 ± 2 dB reference 1 volt/microbar. The hydrophone system is powered by a 12-volt battery.

Table 1 Index of components and test sites.

Device and Manufacturer	Ku Tree Reservoir	Test Facility Doughboy Swimming Pool	Saltwater Test Pool
A. Electric motors			
G.E		✓	
Pacemaker		✓	
B. Relief valves			
Fluid controls IA-32		✓	
Fluid controls IAR-41		✓	
Vickers		✓	
Republic RG 70		✓	✓
Circle Seal P10 [illegible]6		✓	
Rolamite			✓
C. Hydraulic motors			
Char-Lynn	✓		
Lamina	✓		
Planet	✓		
WSI	✓	✓	
Nutron		✓	
D. Pump			
Vickers V30-15		✓	✓
Borg Warner P4-2B		✓	
Delaval IMO		✓	
Racine supervane		✓	✓
Hydrastar			✓
E. Servovalve			
Moog 74		✓	
Moog 35		✓	
Olsen		✓	
Sanders SV-438-10P			✓
F. Servovalve/Motor combinations			
Olsen/Nutron		✓	
Moog 74/WSI		✓	
Moog 35/WSI		✓	
Olsen/WSI		✓	
G. Comparative data			
Vickers vs. Sanders valves			✓
Rolamite vs. Vickers relief valves			✓
Rolamite vs. Sanders relief valves			✓
Hydrastar vs. Vickers pumps			✓
Hydrastar vs. Supervane pumps			✓

To convert from the scope reading to the standard units of dB//microPascal/1Hz/yd, the following relationship was used: dB//1 μPa/1Hz/1 yd = scope reading + 148.2. This relationship is derived as follows: the scope reading is in dB milliwatt (dBm), which is defined as $10 \log 1000 \frac{V^2}{R}$. The following equation is used to convert scope reading to dB volts (dBv):

$$\text{dBm} = 10 \log 1000 \frac{V^2}{50} \qquad \text{where } R = 50 \text{ ohms}$$

$$= 10 \log 20\, V^2$$

$$= 10 (\log 20 + 2 \log V)$$

$$= 13 + 20 \log V$$

$$= 13 + \text{dBv} \qquad \text{where dBv} = 20 \log V$$

therefore:

$$\text{dBv} = \text{dBm} - 13$$

$$= \text{scope reading} = 13$$

A scan bandwidth (BW) of 300 Hz was used. To convert to a 1-Hz BW, 10 log BW must be subtracted from the scope readings. Therefore:

$$\text{dBv}//_{1\,\text{Hz}} = \text{dBm} - 13 - 10 \log \text{BW}$$

$$= \text{dBm} - 13 - 10 \log 300$$

$$= \text{dBm} - 13 - 24.8$$

$$= \text{dBm} - 37.8$$

The spectrum analyzer has a 50-ohm shunt resistor, and when the hydrophone amplifier is plugged into the analyzer the voltage that the scope receives is one-half the open-circuit voltage.

Since voltage into the scope is one-half the hydrophone output, a correction factor, 20 log 2, is added to the scope readings. Therefore:

$$\text{dBv}//_{1\,\text{Hz}} = \text{dBm} - 37.8 + 20 \log 2$$

$$= \text{dBm} - 37.8 + 6$$

$$= \text{dBm} - 31.8$$

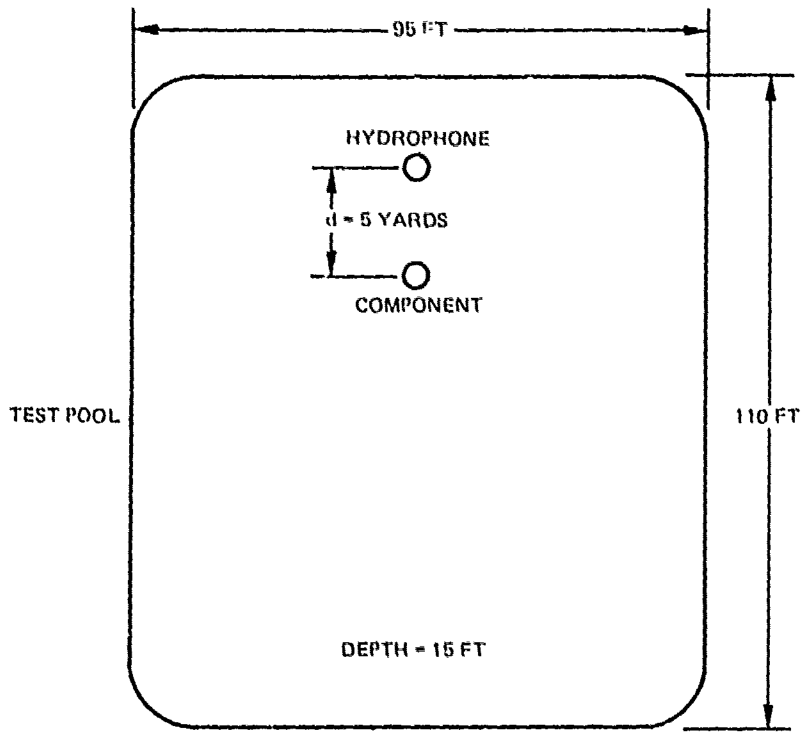


Figure 8. NOSC saltwater test pool layout.

The hydrophone output is fed into a Hewlett-Packard 141T Spectrum Analyzer. A simplified schematic is shown in figure 9.

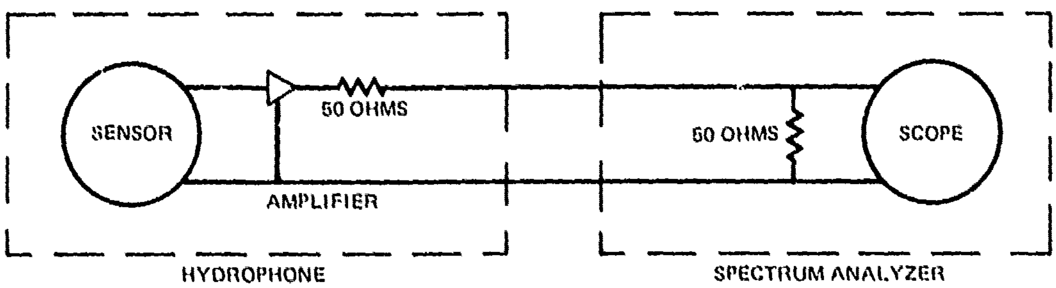


Figure 9. Hydrophone-analyzer simplified schematic.

Hydrophone sensitivity must be subtracted to get the actual sound pressure levels at the hydrophone. Therefore:

$$dB//_{1\ \text{microbar}/1\ \text{Hz}} = \text{dBm} - 31.8 - (-66)$$

$$= \text{dBm} + 34.2$$

To determine the sound pressure levels at one yard spacing, a correction factor, 20 log D, must be added to account for the spreading loss. The absorption loss for five yards spacing is negligible and was not considered. Therefore, where hydrophone spacing D = 5 yards,

$$dB//_{1\ \text{microbar}/1\ \text{Hz}/1\ \text{yd}} = \text{dBm} + 34.2 + 20 \log 5$$

$$= \text{dBm} + 34.2 + 14$$

$$= \text{dBm} + 48.2$$

A microPascal is equivalent to 10^{-5} microbar, so, in dB, the zero reference on the microbar scale is equivalent to 100 dB on the microPascal scale Therefore:

$$dB//_{1\ \text{microPascal}/1\ \text{Hz}/1\ \text{yard}} = \text{dBm} + 48.2 + 100$$

$$= \text{dBm} + 148.2$$

When transposing the acoustic curves from the polaroid pictures to the graphs, 148.2 was added to the dB scale.

COMPONENT TESTS AND RESULTS

The methods that were employed in acoustic testing of the different components are described in the following paragraphs.

RELIEF VALVES

The relief valves tested were set to open at 1000-psi differential pressure. The valves were installed as shown in figure 10 and tested at various flow rates. To determine the effects of higher ambient pressures on the noise output of hydraulic components, simulated high ambient pressure tests were run by increasing return line pressures while maintaining a 1000-psi differential pressure across the valves. Three pressure relief valves were tested at various return line pressures to determine the effects of the higher pressures on noise output.

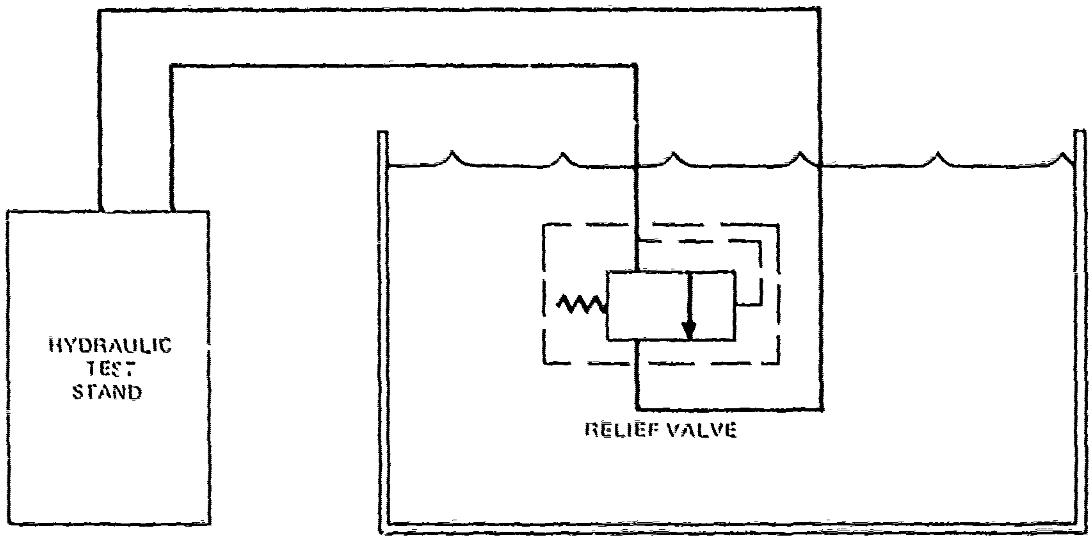


Figure 10. Test schematic: relief valves.

Relief valve test results are shown in graphs B-101 through B-510, B-601 through B-604, G-201 through G-208, and G-301 through G-304 in the appendices.

The Vickers relief valve was tested at return line pressures of 0, 250, 300, 400, 450, and 500 psi. Acoustic data (graphs B-301 through B-315 of appendix A) show that by increasing the return line pressure from 0 to 250 psi, the low frequency (0-40 kHz) noise output was reduced considerably but there was little effect on the higher frequencies. There was no further reduction in low frequency noise output with increasing pressures; however, the mid-range (40-kHz) noise output decreased with increasing pressure up to 400 psi. The high frequency (140-200 kHz) noise output decreased when the pressure was increased from 350 to 450 psi. There was no change in noise output with an increase in pressure from 450 to 500 psi.

The Republic relief valve was tested with return line pressures of 0, 250, 500, and 750 psi, as seen in graphs B-401 through B-408 of appendix A. The low frequency noise output decreased with increasing pressure up to 500 psi; however, there was little or no significant change in noise output with an increase in return line pressure from 500 to 750 psi.

The acoustic data indicate that cavitation noise was probably reduced or eliminated at pressures above 450 psi. It would also appear that operations at depths below 1000 feet, where ambient pressures are greater than 450 psi, will have much lower noise levels than operations nearer the surface. All relief valves were tested at both 0- and 500-psi return pressures to determine their noise output at the surface and at depth.

The results show inconsistencies in some of the curves from tests run under apparently similar operating conditions (graphs B-301 vs B-311 in appendix A). This may have been due to dissolved gases in the hydraulic oil coming out of solution during testing. With less dissolved gases there would be less gaseous cavitation. Foam was observed in the oil reservoir during testing even though the reservoir oil level was sufficiently high and the reservoir was mounted above the pump.

The amount of air dissolved in the oil was not measured during the tests. Components tested with saturated oil may appear noisier than those tested with low gas content. Therefore, the best comparisons are made between components that were tested with 500-psi return line pressure.

A Sanders frictional-throttling servo valve, mode. number SV-438-10P, was acoustically tested in a relief valve mode; i.e., it was used to regulate pressure by throttling the hydraulic oil flow with no extreme load. It was compared with the Vickers relief valve, model number CT-10-C-20 (turbulent-throttling). A comparative evaluation was conducted using degassed oil and oil from an open reservoir.

The Sanders servo valve and the Vickers relief valve test results are shown in graphs B-316 through B-339 and E-401 through F-410 in appendix B. The test results show that the Sanders frictional-throttling valve is much quieter than the Vickers turbulent-throttling valve. The results also suggest that degassed oil makes little, if any, difference in the noise output of the Vickers valve at the lower flow rates, but reduces the noise output by approximately 10 dB at 20 gpm.

The Sanders servo valve and the Vickers relief valve were tested at return line pressures of 0 and 500 psi. Acoustic data (graphs G-101 through G-108 of appendix B) show that there is a large decrease in noise output for the Vickers valve when back-pressured to 500 psi. The data also show that there is no decrease in noise output of the Sanders valve when back-pressured. The Vickers valve, when back-pressured to 500 psi, is as quiet as the Sanders valve at 5 gpm; however, the Sanders valve is approximately 10 dB quieter at the higher flow rates.

With design assistance from Richard A. Milroy of the NSRDC Annapolis Laboratory, a Rolamite pressure relief valve was designed, fabricated, and acoustically tested. In earlier NSRDC tests, Rolamite valves had proved to be comparatively quiet; this experience led to NOSC's interest in the valve for potential use in submersibles. According to Milroy (reference 4), the Rolamite valve achieves quiet frictional throttling with none of the problems of conventional designs, such as close machining, leakage, extreme filtering, etc.

---

4. Milroy, R. A., "ROLAMITE Rolling-Gate Valves", Naval Ship Research and Development Center Report Number 4407, September 1974.

The frictional-throttling Rolamite valve, NOSC drawing number DRS-1000 (appendix D), uses Collimated Hole Structure (CHS), manufactured by Brunswick Corporation, as the throttling element.

The Rolamite valve was designed as a pilot-operated relief valve. The pilot stage was designed into the Rolamite valve, however, the pilot stage designed into the Rolamite housing was not used in the acoustic tests because of its poor performance. The pressure would oscillate approximately 200 psi between 900 psi and 1100 psi, causing an audible squeal on the upward slope of the pressure cycle. The pilot stage was made nonfunctional by adjusting the loading screw to place a large load on the pilot stage spring. A remote relief valve was connected to the control port and used as a remote pilot stage (figure 11), the Rolamite valve then operated steadily. The remote relief valve was not submerged during the acoustic tests and it did not contribute to the acoustic output of the Rolamite valve.

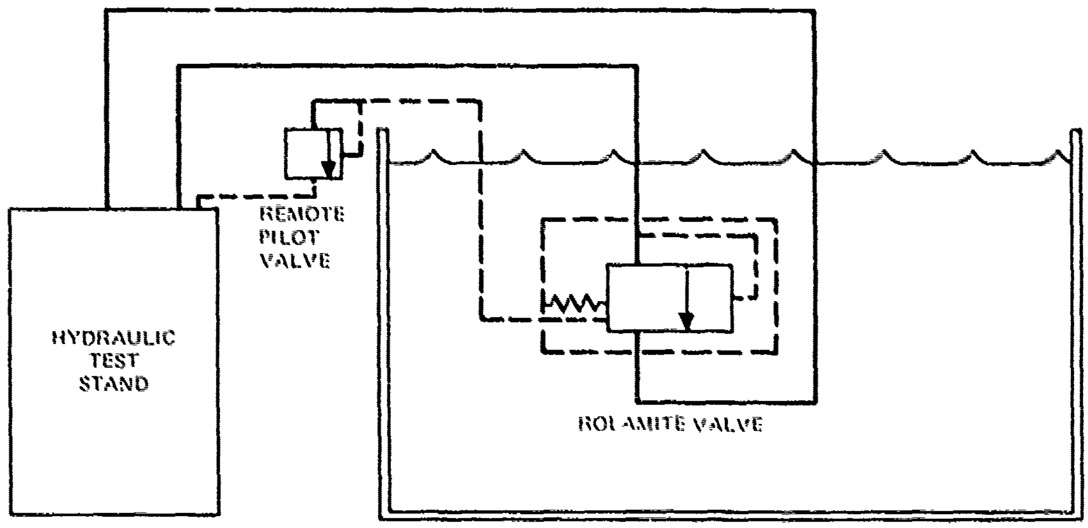


Figure 11. Rolamite valve test arrangement.

Graphs B-601 through B-604 in appendix B show that the Rolamite valve had its highest acoustic output at 10 gpm and was quieter at the higher flow rates. This characteristic may be due to the arrangement of the CHS throttling elements (appendix D). As shown in appendix D, the two throttling elements are separated by a plenum ring forming a plenum chamber. Flow through the elements is regulated by the amount the band is uncovered on the first element. For all flow rates, the flow area of the second element remains the same. Therefore, the pressure drop across the second element varies proportionally with the flow, the higher the flow, the greater the pressure drop. The second element is effective at the higher flow rates and not at the low rates. However, at 10 gpm, the second element may not have enough effect over the increased turbulence to keep the noise level as low as it is at 5 gpm.

Graphs G-201 through G-204 (appendix C) clearly show that the Rolamite valve is much quieter near the surface than the Vickers relief valve at normal operating conditions.

Graphs G-205 through G-208 show that at higher ambient pressures, where cavitation is reduced in the Vickers valve, the difference is much less, however, the Rolamite valve still is quieter.

Graphs G-301 through G-304 (appendix C) show that the Rolamite is generally quieter than the Sanders servo valve except at frequencies above 30 kHz for the 10-gpm flow rates, and above 130 kHz at the 20-gpm flow rates

MOTORS

The hydraulic motors were tested at various power levels to simulate the loading characteristics of the submersible propulsion units. To simulate propeller loading without creating the usual propeller turbulence, 1/16-inch thick aluminum disks were attached to the motor shafts (figure 12). A tachometer sending unit was also attached to the shaft to monitor shaft rpm. Several disks having different diameters were available. Each disk was experimentally calibrated to determine the torque required to rotate it at a given rpm while submerged in water. The torque vs rpm curves of the various disks were used to select a propeller simulator that would present the proper amount of loading for a given motor.

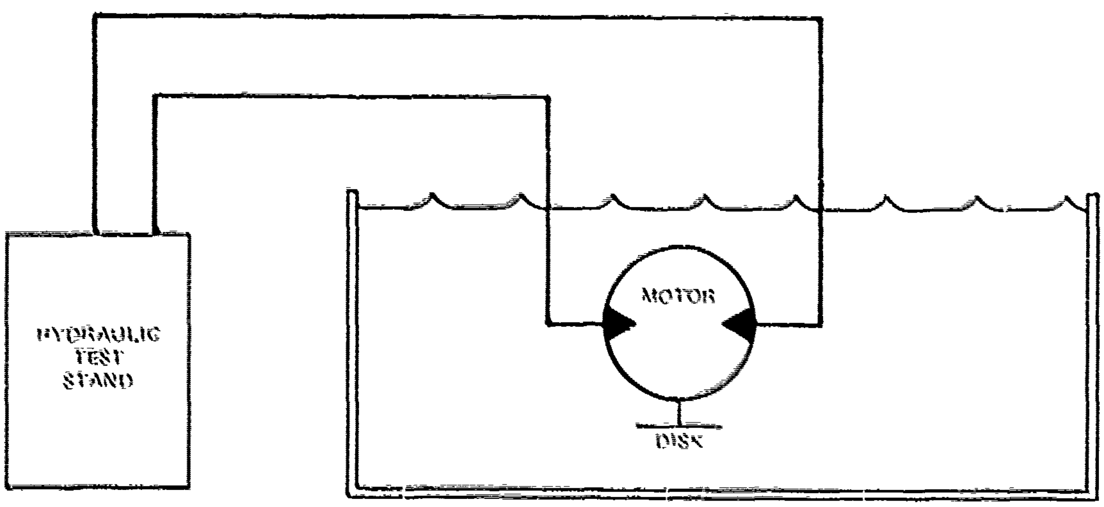


Figure 12. Test schematic – motors.

Several motors were tested which would have required speed reducers to match the propeller drive requirements, hence the need for disks giving several speed torque curves. The horsepower required to drive the disks at various rpms was calculated from the torque and rpm data, and curves of horsepower vs rpm were plotted. These data are presented in figures 13 and 14.

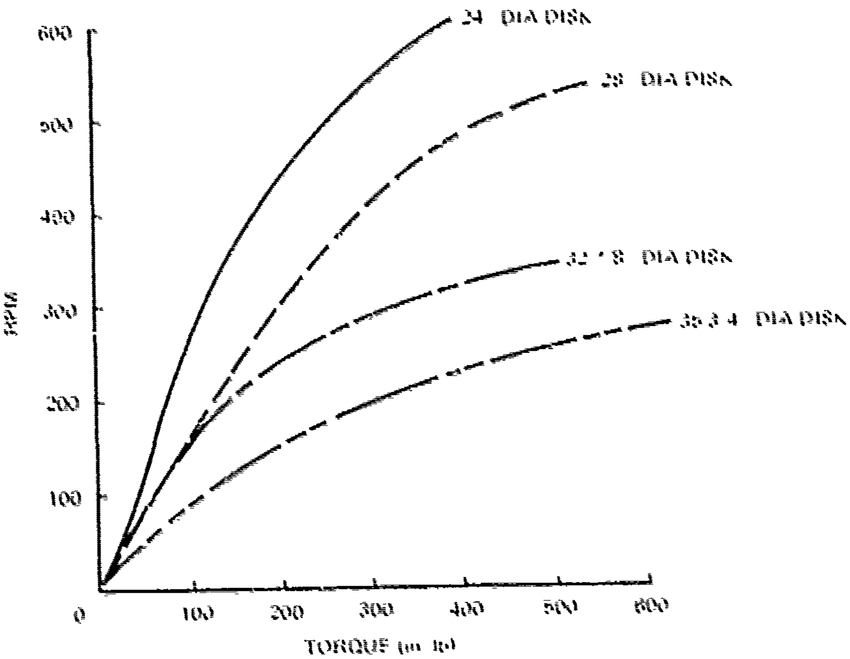


Figure 13. Disk data (rpm vs torque)

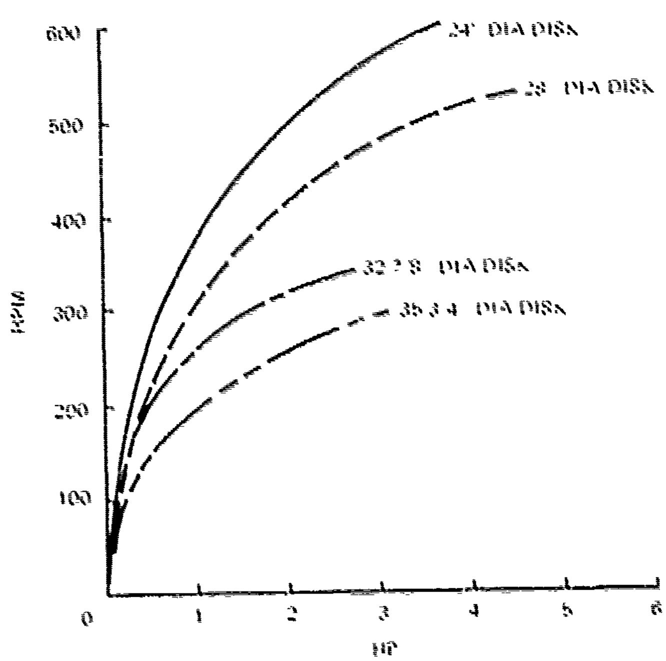


Figure 14. Disk data (rpm vs hp)

The types of motors tested included the following:

MOTOR	TYPE	DISP (in^3/rev)	WEIGHT (lb)
Washington Scientific Industries	Axial Rolling Vane	3.42	26
Nutron	Axial Ball Piston	2.8	30
Char-Lynn	Geroler	3.0	11
Lamina	Gerotor	3.[illegible]	3.34
Planet	Radial Ball Piston	0.93	10.14

Initial testing of the motors was conducted at Ku Tree Reservoir and the results are shown in graphs C-101 through C-104 of appendix A. The results showed the Washington Scientific Industries (WSI) motor was, by far, the quietest of all the motors tested.

Due to the time scheduling it was felt that no further effort should be spent on the noisier motors and that they could be eliminated as candidate components. Therefore, when testing was resumed in the swimming pool and when the Nutron motor was acquired, only the WSI motor was retested for comparison with the Nutron motor. The WSI motor was quieter than the Nutron motor and was selected for use on RUWS. Swimming pool test results are shown in graphs C-408 through C-417 of appendix A.

PUMPS

The pumps selected for the evaluation were tested at 1750 rpm and 1000 psi output pressure. The test pumps were mounted and direct-coupled to a 1750-rpm electric motor in a cylindrical housing. This arrangement simulates the actual RUWS motor pump configuration. Hydraulic lines were routed to a pressure gage and flowmeter to monitor the pressure and flow output, and relief valve was used to control the pressure. The meters and valve were mounted on a fixture not directly connected to the pool so the noise they produced was not transmitted to the water.

The test units were connected as shown in figure 18.

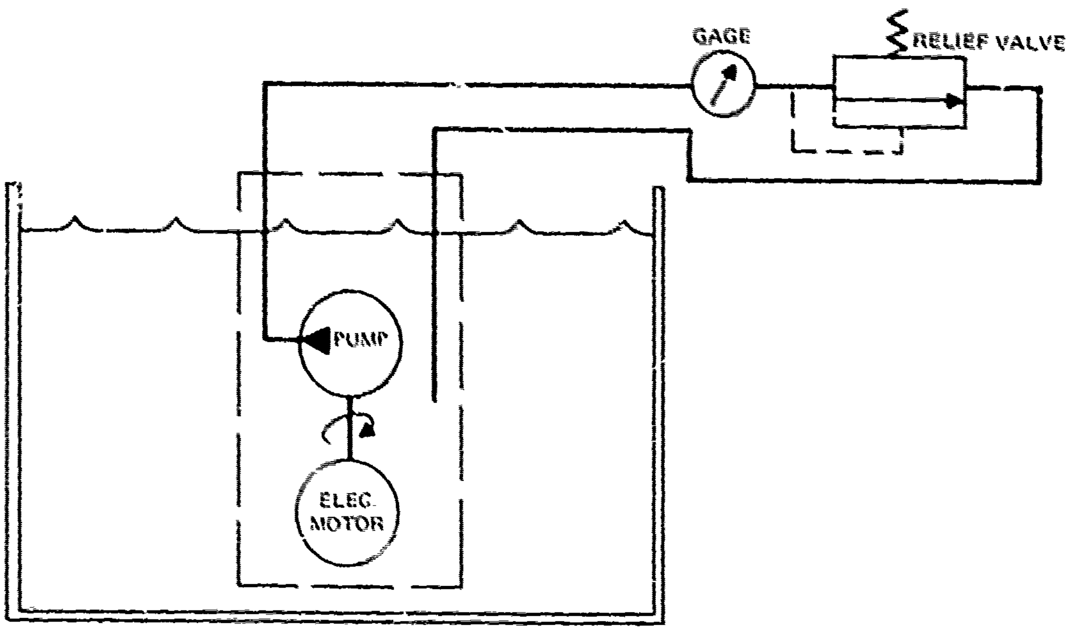


Figure 15. Test schematic: pumps.

SERVO VALVES

The servo valves were initially tested by connecting their control ports together, as shown in figure 16, and connecting the 1000-psi pressure across the valve. Hydraulic flow through the valve was adjusted by varying the electrical supply voltage. This method of testing did not simulate the actual use conditions. The full 1000-psi pressure was being dropped across ports C1 and C2, 500 psi at each port. In the actual system, the 1000-psi pressure drop would be divided between the hydraulic motor and the servo valve; the pressure drops across each would depend on the amount of flow through the valve to the motor. In the "final system" test (figure 17), the control ports were connected to a hydraulic motor. Part of the 1000-psi pressure drop then occurred across the hydraulic motor, and part occurred across the valve. The measured noise output was taken as the combined noise output of the motor and the servo valve. The aluminum disk propeller simulator was mounted on the motor shaft to load the motor without creating the turbulence and thrust inherent in a rotating propeller.

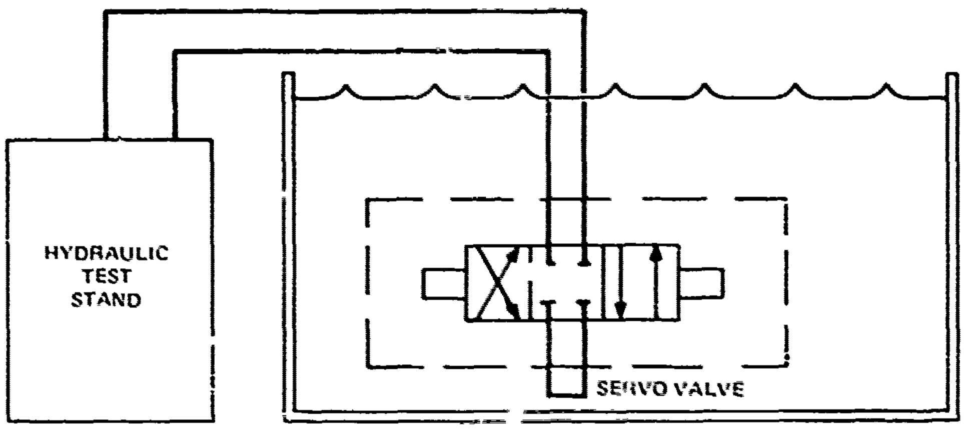


Figure 16. Test schematic: servo valves (initial configuration).

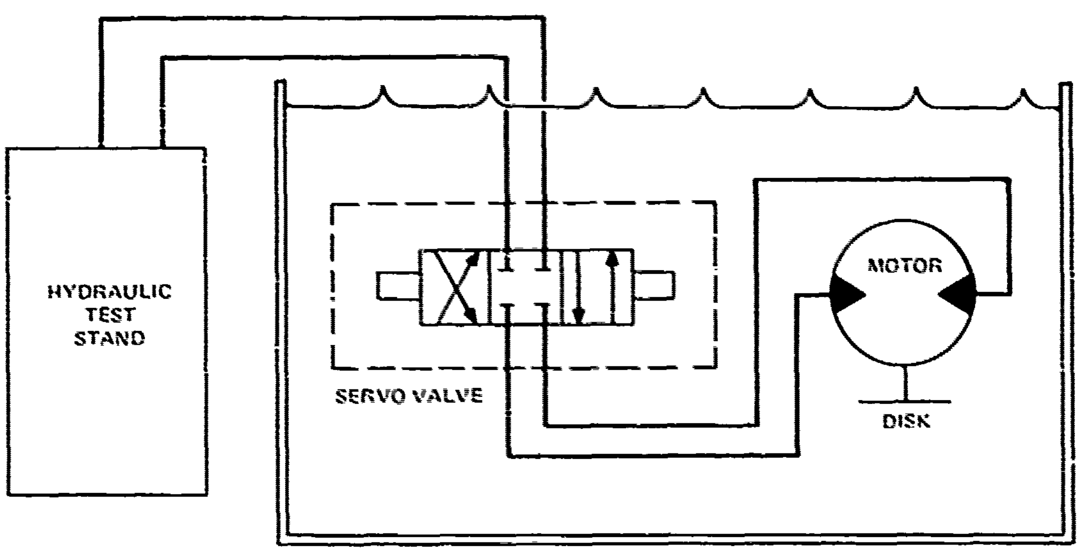


Figure 17. Test schematic: servo valve/motor (final configuration).

Results of the servo valve tests are shown in graphs E-101 through E-310 of appendix A. Test results of servo valves and motors in the final test configuration are shown in graphs F-101 through F-413 of appendix A. In this configuration, the highest noise levels were produced at low motor rpm where the largest pressure drop occurred across the servo valve. When the motors were run at the higher speeds, more pressure was dropped across the motors, resulting in lower noise outputs. The Olsen-WSI combination exhibited the lowest noise output and was selected for use on RUWS.

COMPONENTS SELECTED FOR USE ON RUWS

The components selected for the initial construction of the vehicle in 1973, after the first component acoustic test series in the doughboy swimming pool were done, were:

1. Vickers pump

2. Vickers relief valve

3. Olsen servo valves

4. Washington Scientific Industries motors

The types of pumps tested included the following:

PUMP	TYPE	DISPLACEMENT	WEIGHT
Vickers	Vane, fixed-displacement	20 gpm	34
Borg-Warner	Gear, fixed-displacement	24 gpm	27
DeLaval	Screw	10 gpm @ 1000 psi	121
Racine	Vane, pressure-compensated	13 gpm @ 0 psi	62
Hydrastar	Gear, fixed-displacement	20 gpm	60

Test results are shown in graphs D-101 through D-404 of appendix A. The DeLaval pump was the quietest pump tested. However, it had high internal leakage and it was also the heaviest pump tested.

The Vickers pump was originally selected for RUWS. This pump was also tested with 500-psi inlet pressure, which resulted in a significantly lower acoustic output; however, the acoustic output for that test was recorded only up to 100 kHz. The reduction in acoustic output is probably due to a reduction in internal and inlet cavitation noise.

The Racine pump was originally tested only to evaluate that type of pump, a pressure-compensated, variable-displacement design. It has a lower acoustic output than any fixed-displacement vane pump tested.

Laboratory operation of the RUWS system has since shown that changes in electrical load at the vehicles are tolerable. A pressure-compensated, variable-displacement pump would therefore offer a significant noise reduction. In addition, its use would eliminate the flow through the relief valve and the inherent noise caused by the throttling of the flow.

A Hydrastar pump, model 5-HI-20G, manufactured by Hartrum Corporation, also was acoustically tested. This pump was direct-coupled to a 1750-rpm GE electric motor and run in the oil-filled motor pump container. The tests were conducted in June 1975 at the NOSC saltwater test pool. Graphs D-501 through D-503 show that the Hydrastar pump is quietest at a 500-psi load, and noisiest at no load (0 psi).

Graph G-401 shows that the Vickers pump is quieter than the Hydrastar pump up to 20 kHz; above 20 kHz, the Hydrastar pump is quieter.

Graph G-501 shows that the Racine supervane pump is quieter than the Hydrastar pump.

After installation and checkout, the vehicle was acoustically tested with the hydrophone mounted on the front of the foam pack where the vehicle search sonar (VSS) ultimately would be mounted. Testing was done in Kaneohe Bay, and sea level measurements were recorded. To simulate 1000-foot depth operations, the hydraulic system was pressurized to 500 psi. The results are shown in figure 18.

Since 1973, when the hydraulic components were selected, component acoustic tests have continued. Because of the new OSHA regulations on noise in the working environment, hydraulic component manufacturers have been expending greater efforts in designing quieter hydraulic components. Quiet hydraulics development has also been continuing at Navy laboratories.

Component acoustic tests have continued on pumps and valves which were the major noise producers. Commercial pumps advertised by the manufacturers to be quiet were tested, as were valves incorporating quiet throttling techniques. As a result of these continuing tests a new Silentvane model Racine pump has been selected to replace the Vickers vane pump.

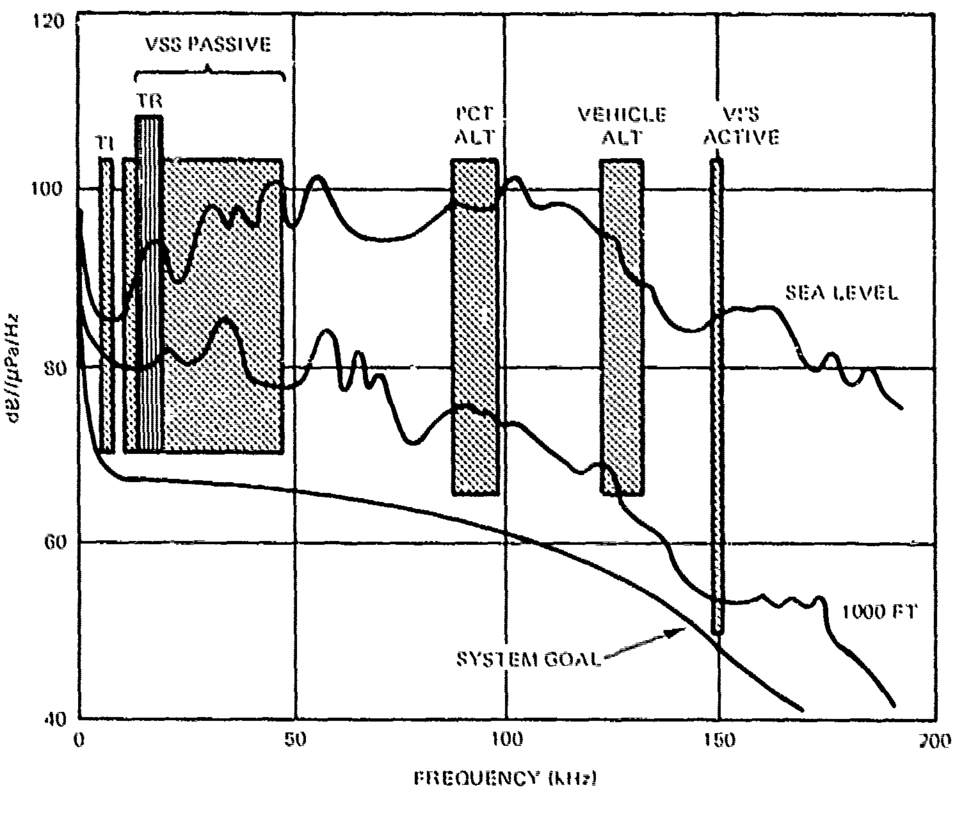


Figure 18. Electrohydraulic acoustic spectrum for RUWS.

CONCLUSIONS

There are several mechanisms of noise generation in hydraulic systems. The major mechanisms are cavitation, machinery and fluid flow.

In hydraulic components and systems of which noise was not a design consideration, cavitation could be the most serious noise source. Cavitation occurs when, at some point in the system, the local pressure is less than the vapor pressure of the hydraulic fluid and bubbles are formed. This can occur in areas of high velocity flow and intense turbulence. Then, at a point downstream, the pressure rises above the vapor pressure and the bubble collapses (implodes) producing broad band noise extending from the audible into the inaudible frequency ranges.

By maintaining the pressure throughout the system at a level high enough that even in areas of intense turbulence the local pressure does not drop below the vapor pressure of the fluid, cavitation would be eliminated. The components tested showed a reduction in noise output when return line pressures were maintained above 450 psi. This is the condition of submersible hydraulic systems that have reservoirs compensated to ambient pressure in the deep ocean. It may also be accomplished with a closed system with a sealed reservoir pressurized to 450 psi.

Hydraulic components are being designed and produced without a tendency for cavitation. Sharp-edged orifice valves are highly susceptible to cavitation because of the high fluid velocities and turbulence on the exit side of the orifice. Several throttling techniques using small-cross-section multiple paths are presently employed by manufacturers making quiet throttling valves. These techniques keep flow velocities and turbulence at levels which do not produce cavit .ion.

REFERENCES

1. Marrone, R. A., J. Held, and R. W. Uhrich, "Manipulator, Grabber and Tools for the RUWS Work Subsystem", NUC TN 818, Volume 2, November 1972.*

2. Volberg, H. W., "Specifications for Vehicle Search Sonar (VSS) Equipment", NUC Hawaii Laboratory, Code 6531, December 1971.

3. Volberg, H. W., "Specification for Long Range Tracking Sonar (LRTS) and Altimeter Equipment for the Remote Unmanned Work System", NUC Hawaii Laboratory, Code 6531, February 1972.

4. Milroy, R.A., "ROLAMITE Rolling-Gate Valves", Naval Ship Research and Development Center Report Number 4407, September 1974.

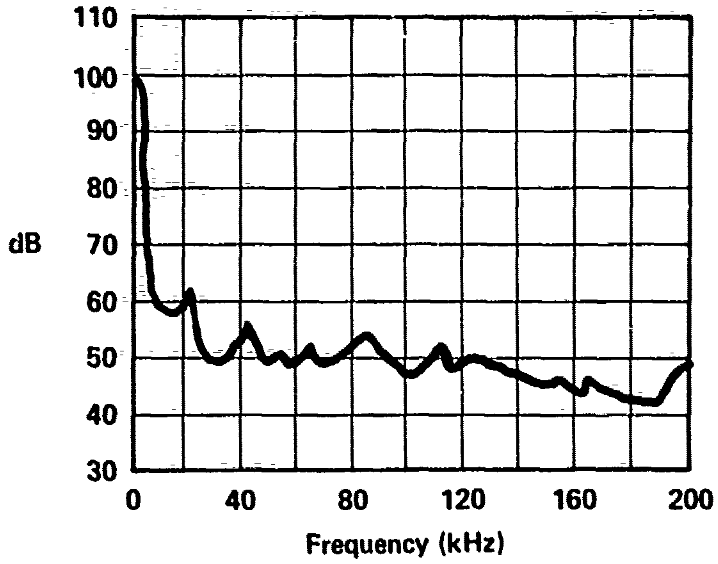
*TNs are informal documents intended chiefly for internal use.

APPENDIX A

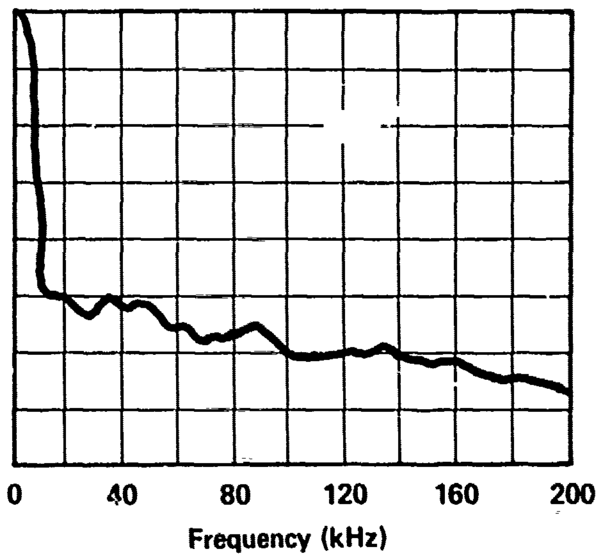
TEST DATA OF FIRST TEST SERIES

GRAPHS

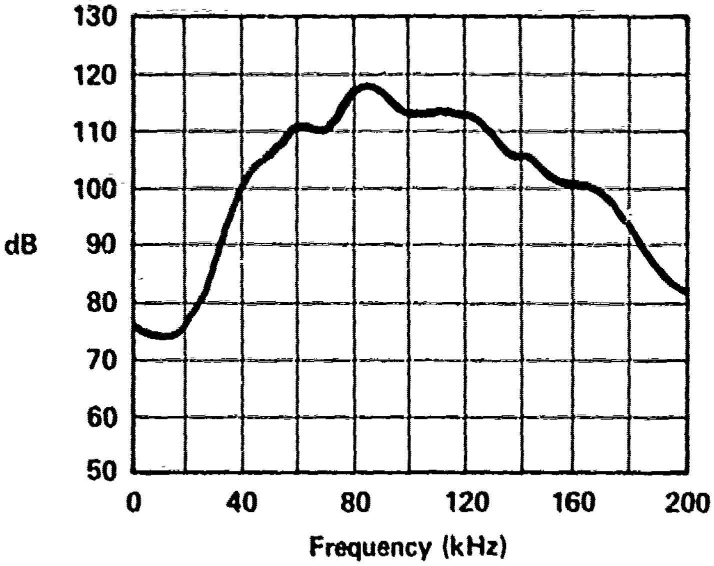
This appendix presents the results of the first series of acoustic tests, depicted by noise profile graphs for each of the components and specified test conditions. The decibel scales for all graphs have a reference of 1 microPascal per hertz per yard (dB//μPa/Hz/yd).



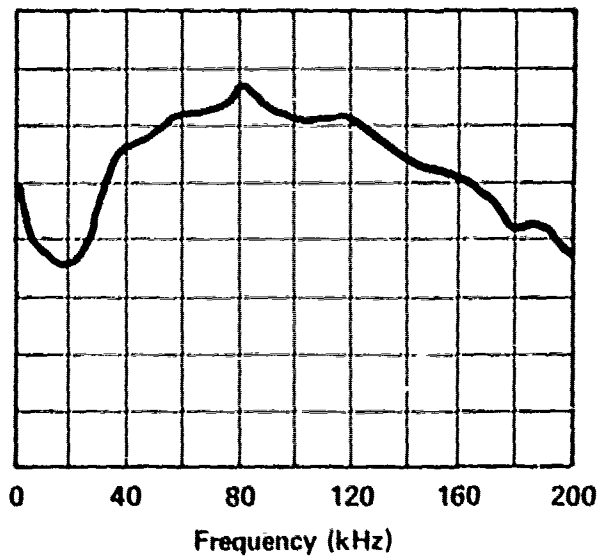
ELECTRIC MOTOR – GENERAL ELECTRIC
MOTOR SPEED – 1750 RPM
A-101



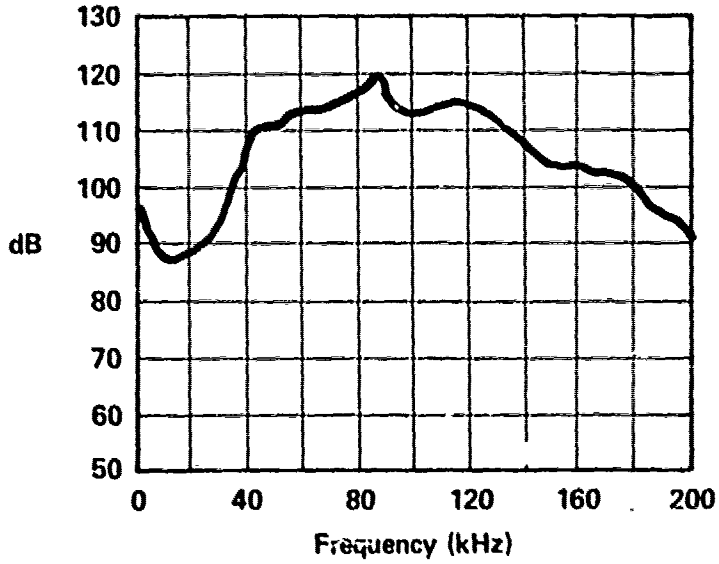
ELECTRIC MOTOR – PACEMAKER
MOTOR SPEED – 3450 RPM
A-102



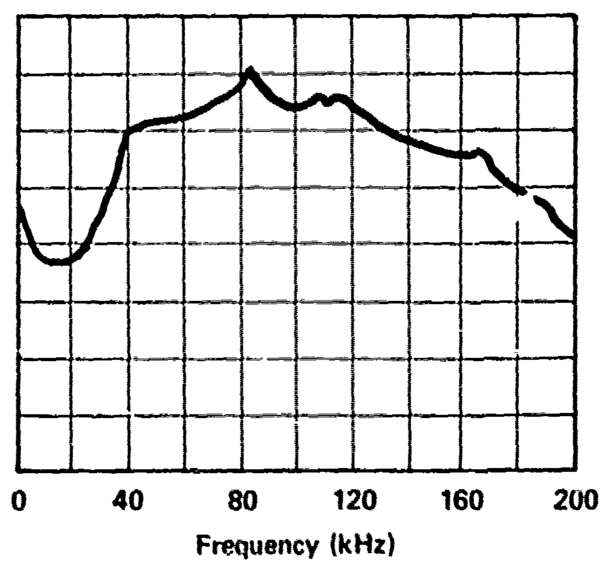
RELIEF VALVE – FLUID CONTROLS 1A-32
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 5 GPM
B-101



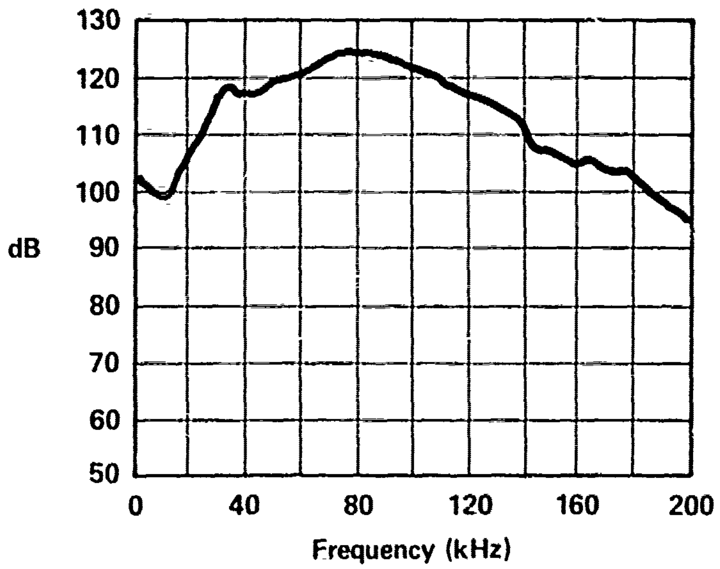
RELIEF VALVE – FLUID CONTROLS 1A-32
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 10 GPM
B-102



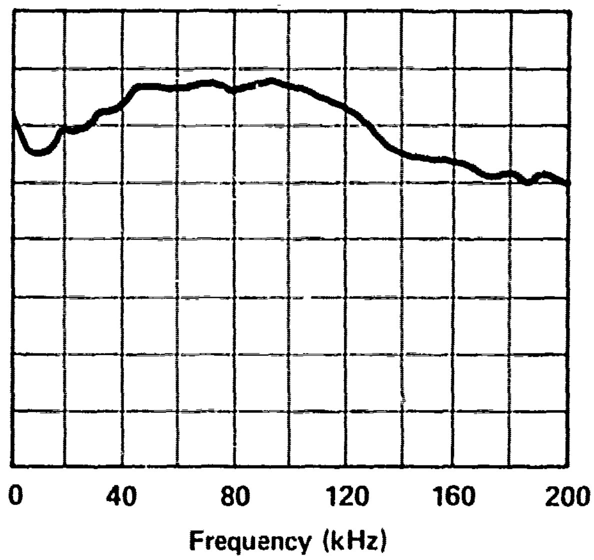
RELIEF VALVE – FLUID CONTROLS 1A-32
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 15 GPM
B-103



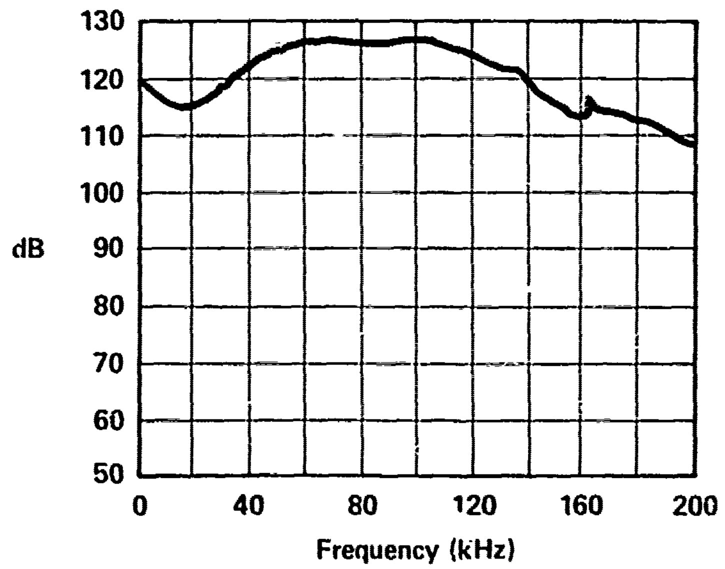
RELIEF VALVE – FLUID CONTROLS 1A-32
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 20 GPM
B-104



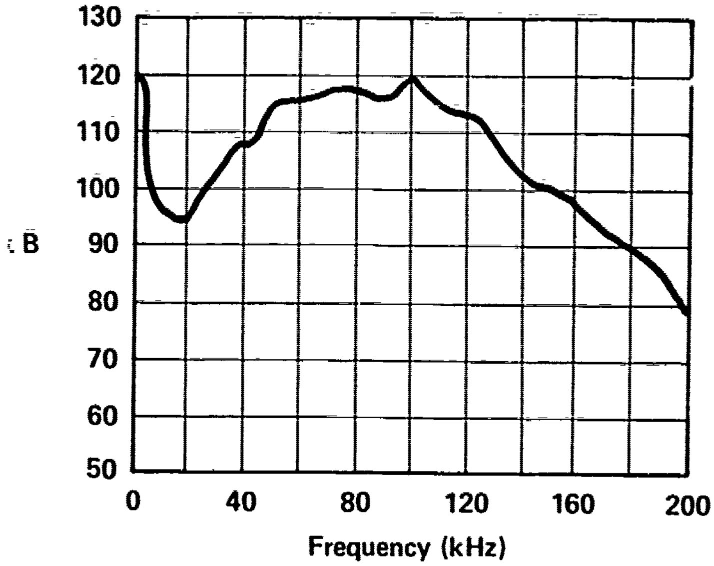
RELIEF VALVE – FLUID CONTROLS 1AR-41
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 5 GPM
B-201



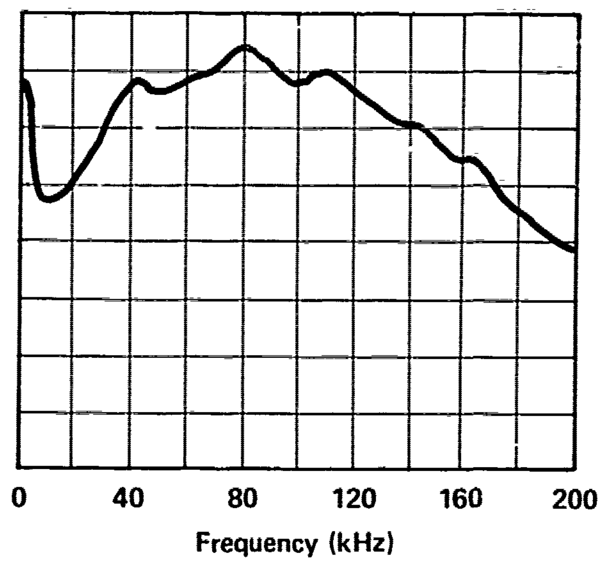
RELIEF VALVE – FLUID CONTROLS 1AR-41
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 10 GPM
B-202



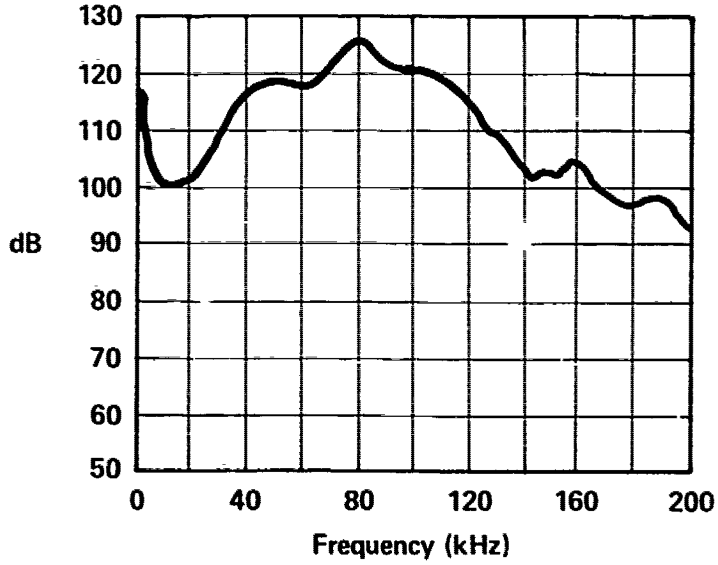
RELIEF VALVE – FLUID CONTROLS 1AR-41
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 15 GPM
B-203



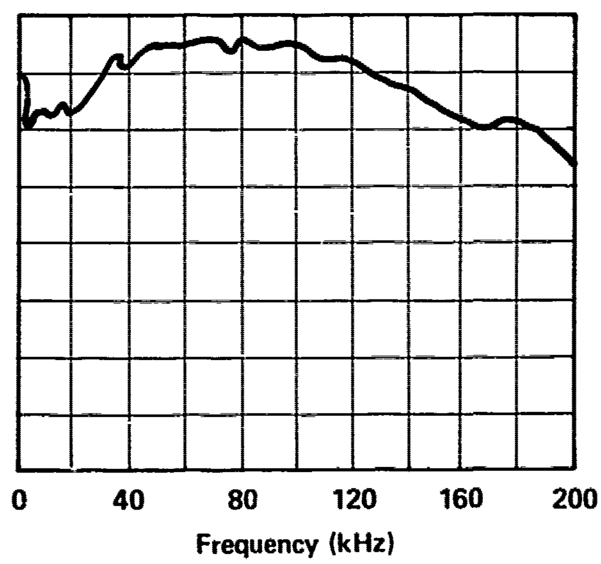
RELIEF VALVE – FLUID CONTROLS 1AR-41
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 5 GPM
B-204



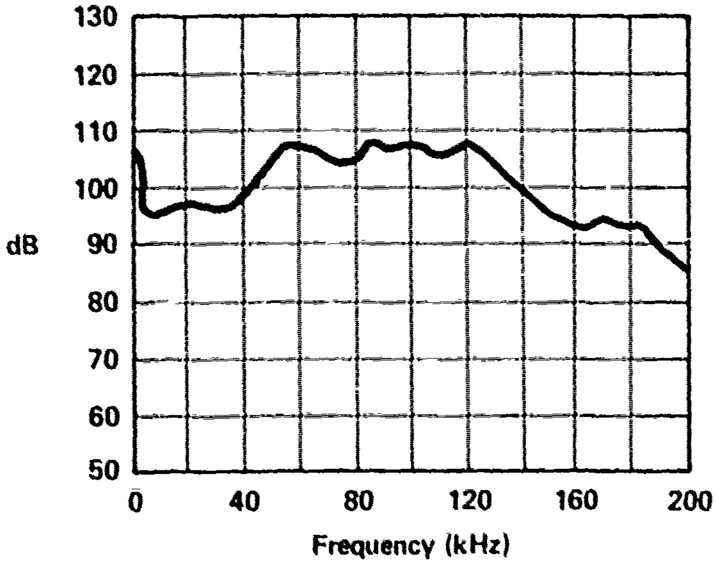
RELIEF VALVE – FLUID CONTROLS 1AR-41
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 10 GPM
B-205



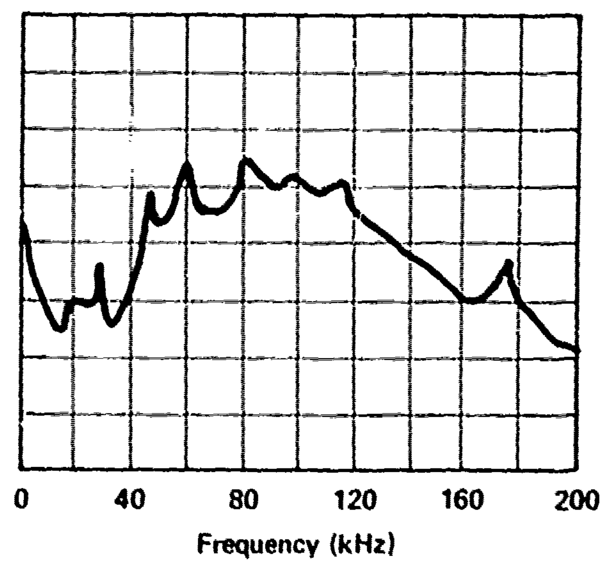
RELIEF VALVE – FLUID CONTROLS 1AR-41
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 15 GPM
B-206



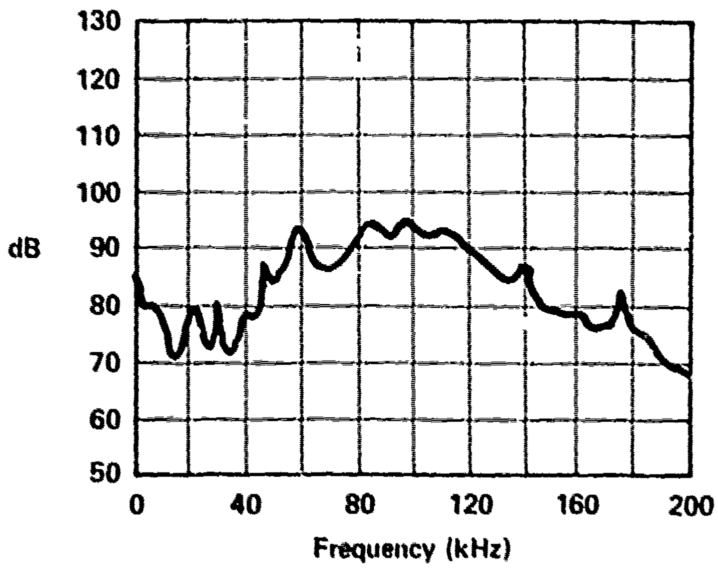
RELIEF VALVE – FLUID CONTROLS 1AR-41
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 20 GPM
B-207



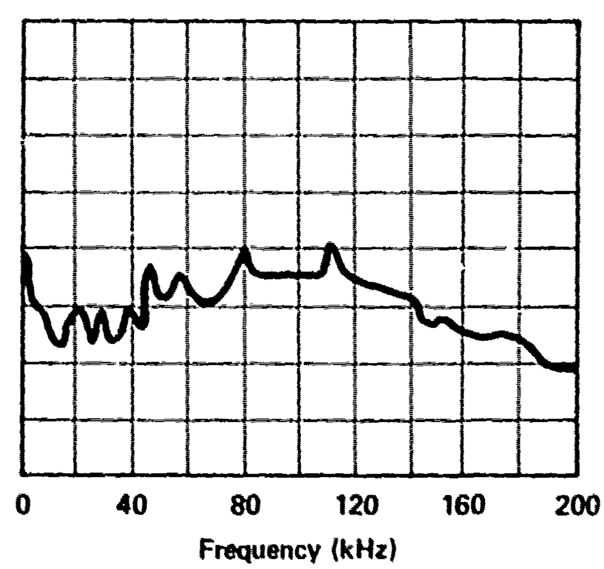
RELIEF VALVE – VICKERS
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 20 GPM
B-301



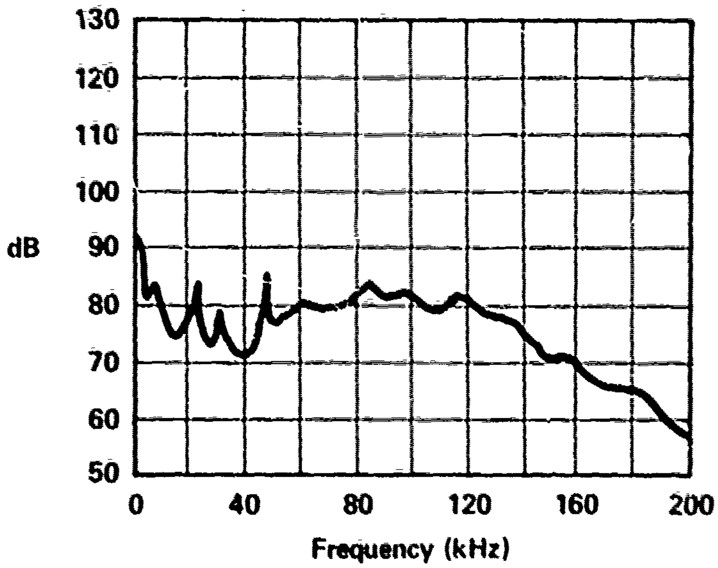
RELIEF VALVE – VICKERS
INLET PRESSURE – 1250 PSI
RETURN PRESSURE – 250 PSI
FLOW TO VALVE – 20 GPM
B-302



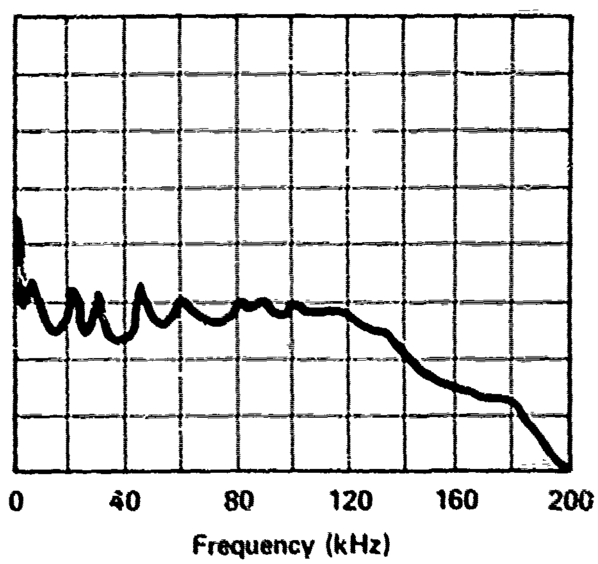
RELIEF VALVE – VICKERS
INLET PRESSURE – 1300 PSI
RETURN PRESSURE – 300 PSI
FLOW TO VALVE – 20 GPM
B-303



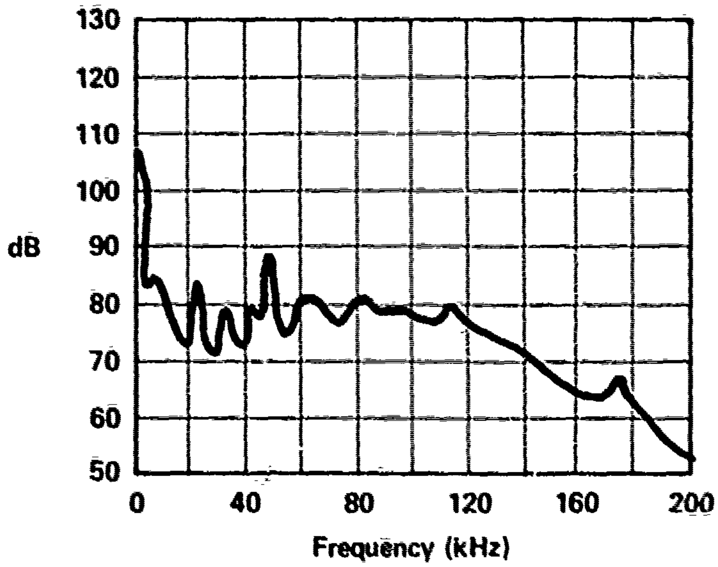
RELIEF VALVE – VICKERS
INLET PRESSURE – 1350 PSI
RETURN PRESSURE – 350 PSI
FLOW TO VALVE – 20 GPM
B-304



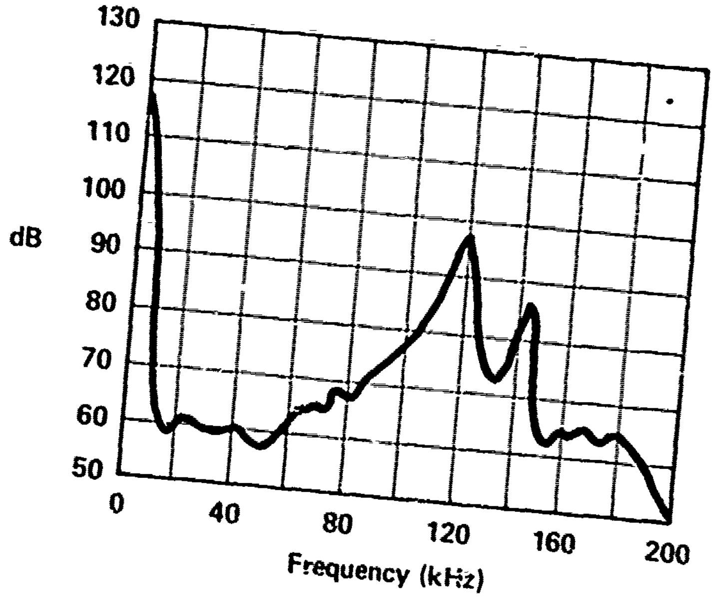
RELIEF VALVE – VICKERS
INLET PRESSURE – 1400 PSI
RETURN PRESSURE – 400 PSI
FLOW TO VALVE – 20 GPM
B-305



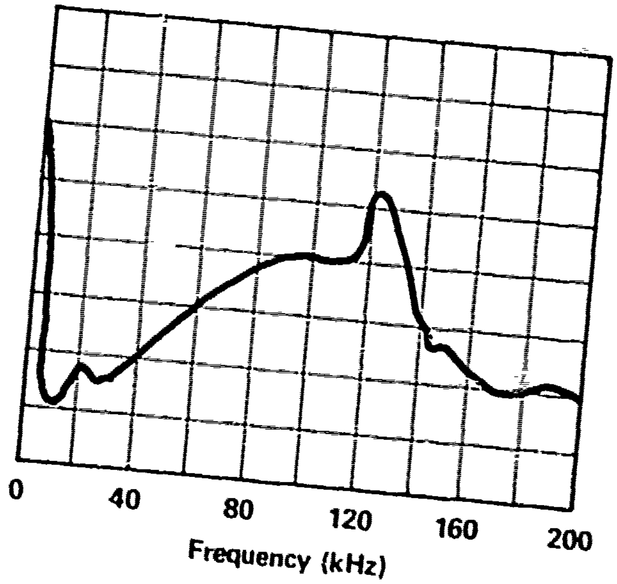
RELIEF VALVE – VICKERS
INLET PRESSURE – 1450 PSI
RETURN PRESSURE – 450 PSI
FLOW TO VALVE – 20 GPM
B-306



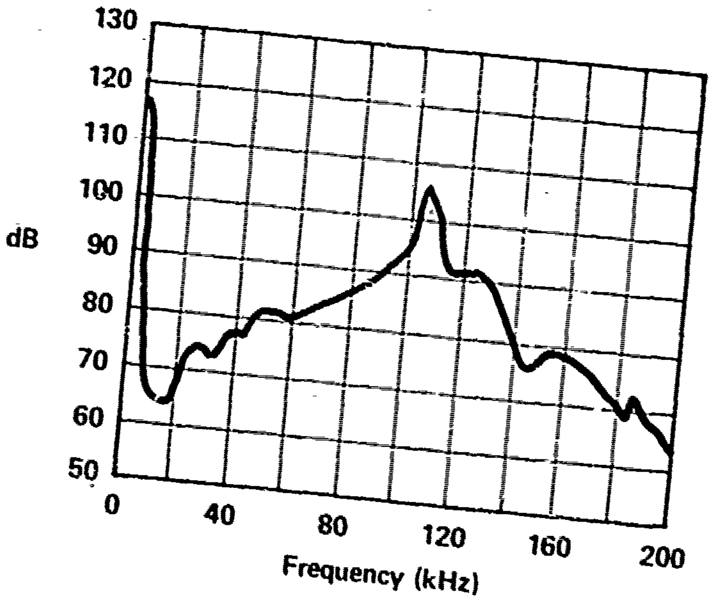
RELIEF VALVE – VICKERS
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 20 GPM
B-307



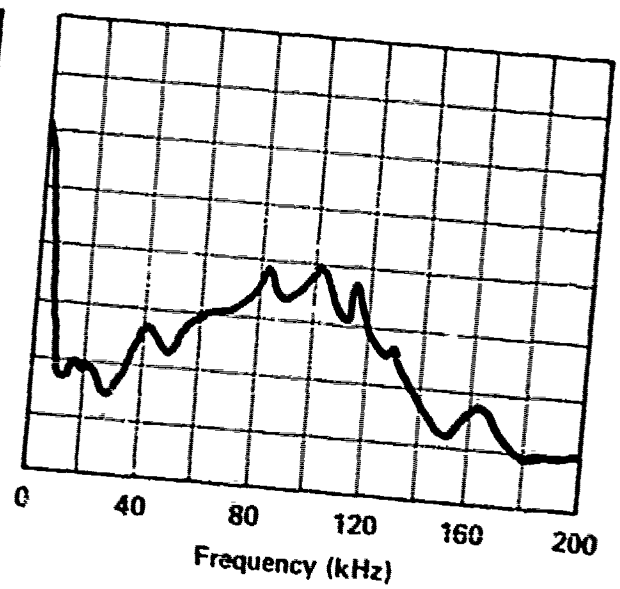
RELIEF VALVE – VICKERS
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 5 GPM
B-308



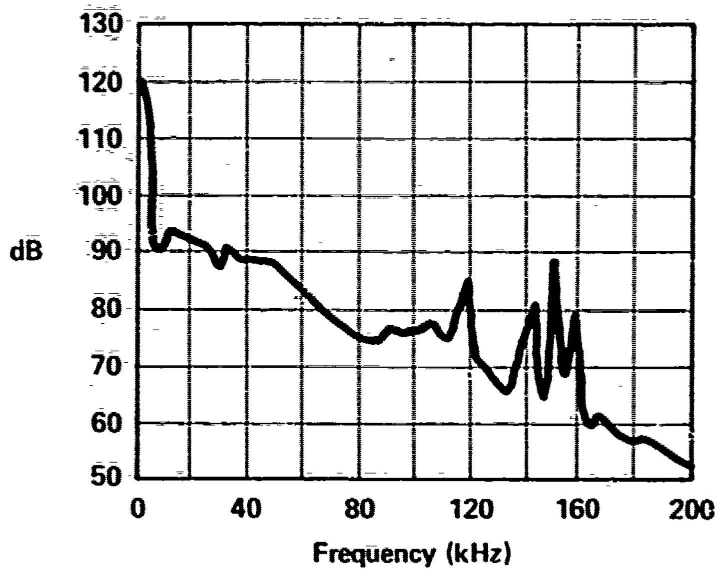
RELIEF VALVE – VICKERS
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 10 GPM
B-309



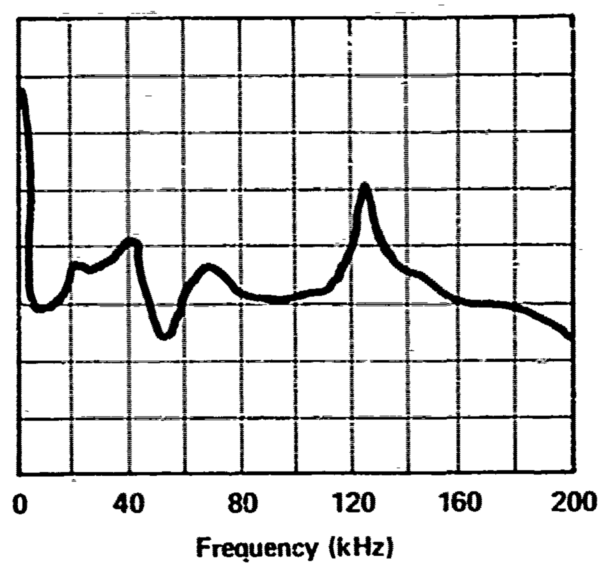
RELIEF VALVE – VICKERS
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 15 GPM
B-310



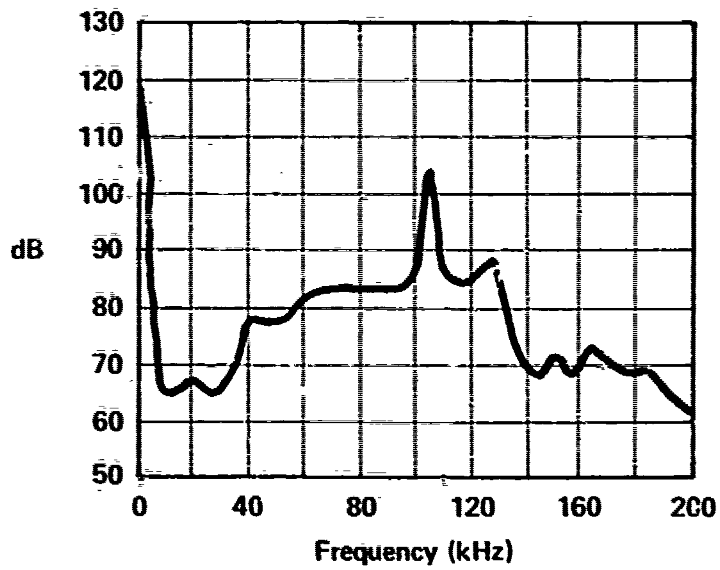
RELIEF VALVE – VICKERS
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 20 GPM
B-311



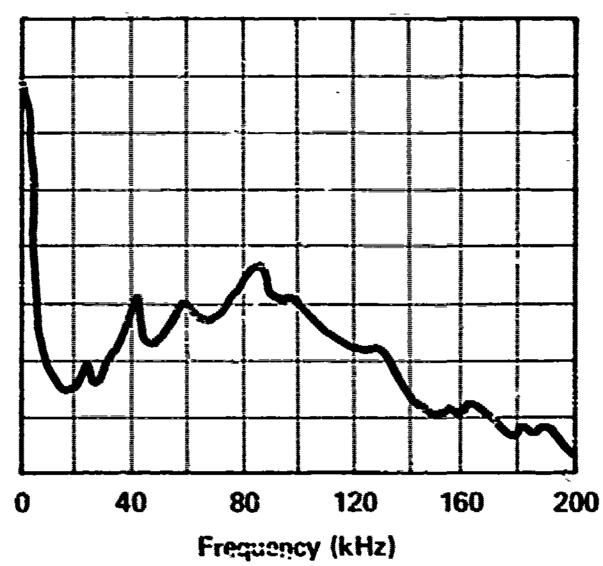
RELIEF VALVE – VICKERS
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 5 GPM
B-312



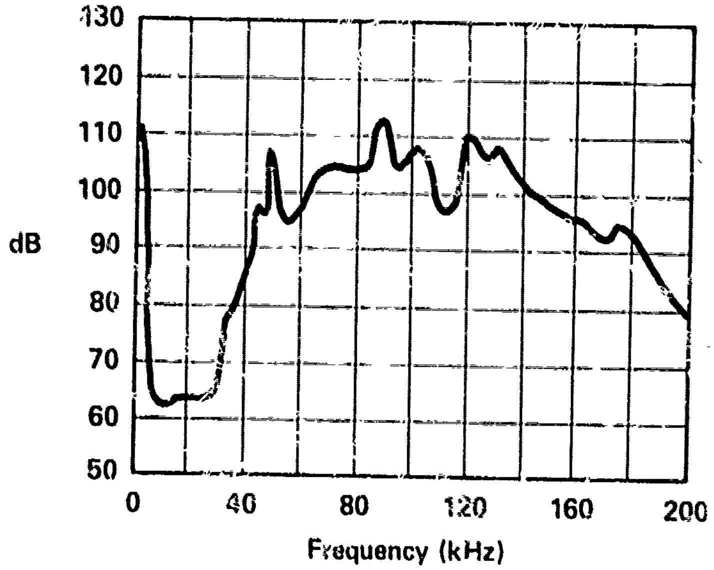
RELIEF VALVE – VICKERS
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 10 GPM
B-313



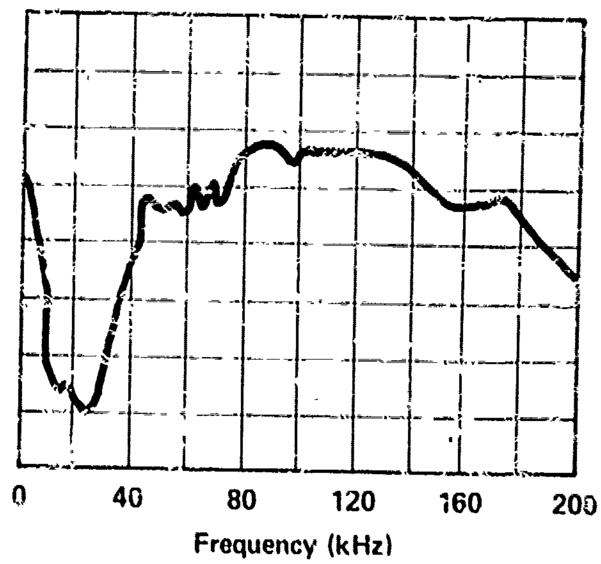
RELIEF VALVE – VICKERS
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 15 GPM
B-314



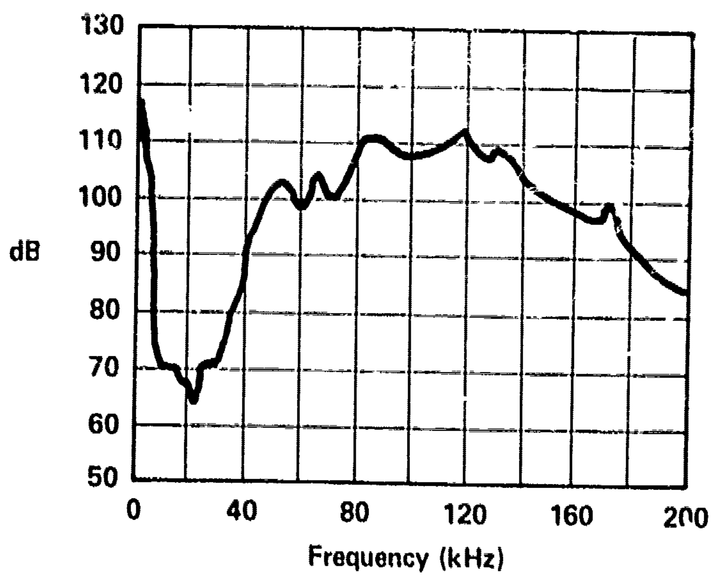
RELIEF VALVE – VICKERS
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 20 GPM
B-315



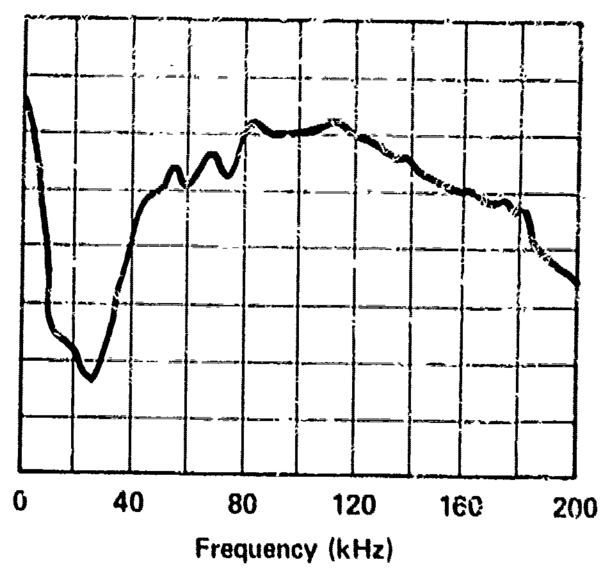
RELIEF VALVE – REPUBLIC RG70
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 5 GPM
B-401



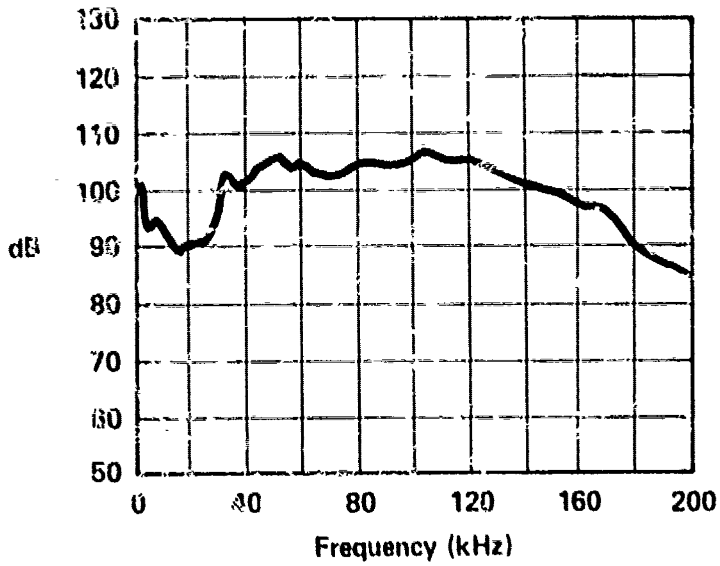
RELIEF VALVE – REPUBLIC RG70
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 10 GPM
B-402



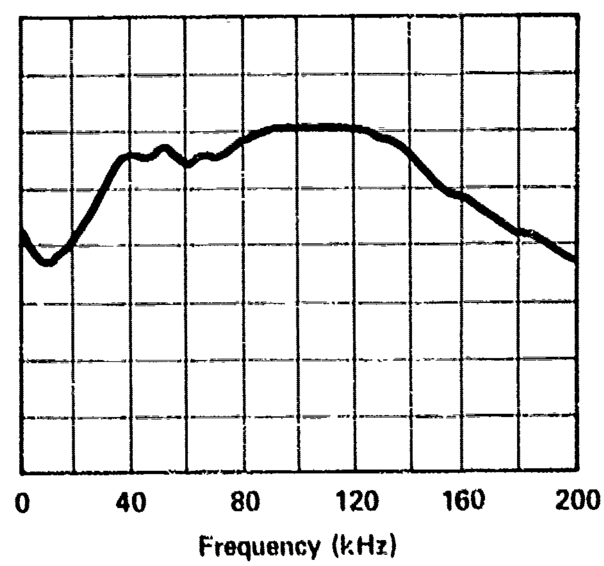
RELIEF VALVE – REPUBLIC RG70
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 15 GPM
B-403



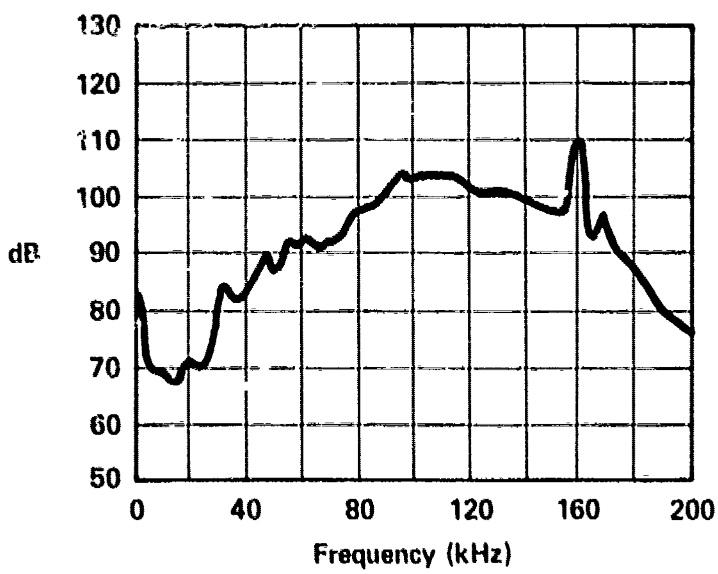
RELIEF VALVE – REPUBLIC RG70
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 20 GPM
B-404



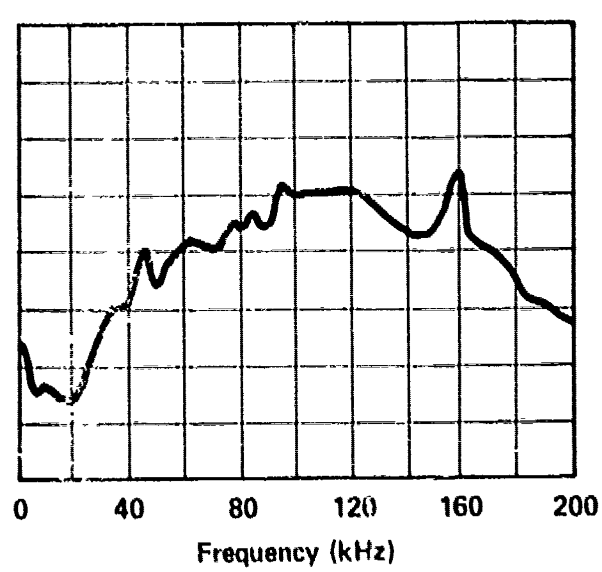
RELIEF VALVE - REPUBLIC RG70
INLET PRESSURE – 1000 PSI
RETURN PRESSURE - 0 PSI
FLOW TO VALVE – 10 GPM
B-405



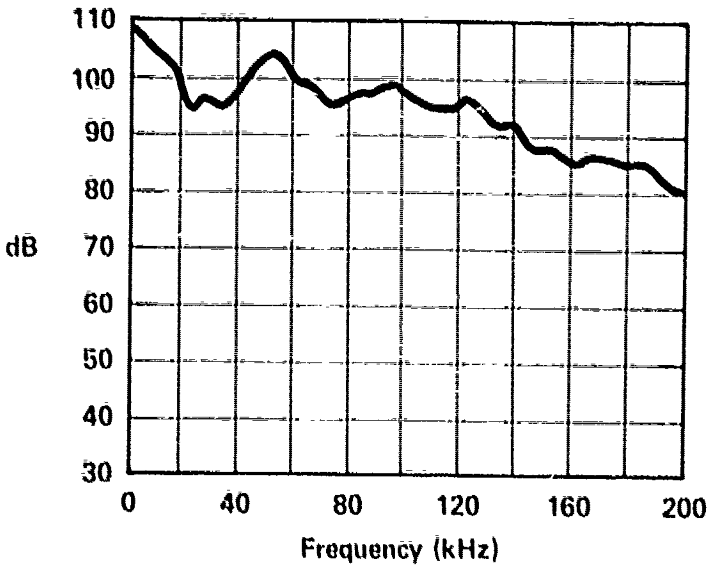
RELIEF VALVE – REPUBLIC RG70
INLET PRESSURE – 1250 PSI
RETURN PRESSURE – 250 PSI
FLOW TO VALVE – 10 GPM
B-406



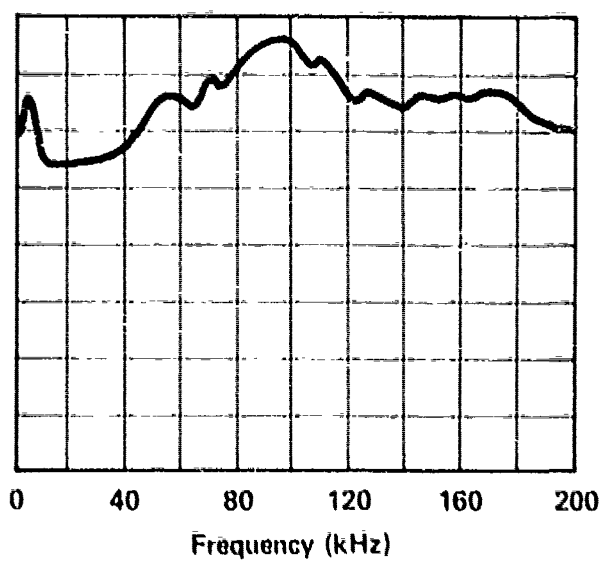
RELIEF VALVE – REPUBLIC RG70
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 10 GPM
B-407



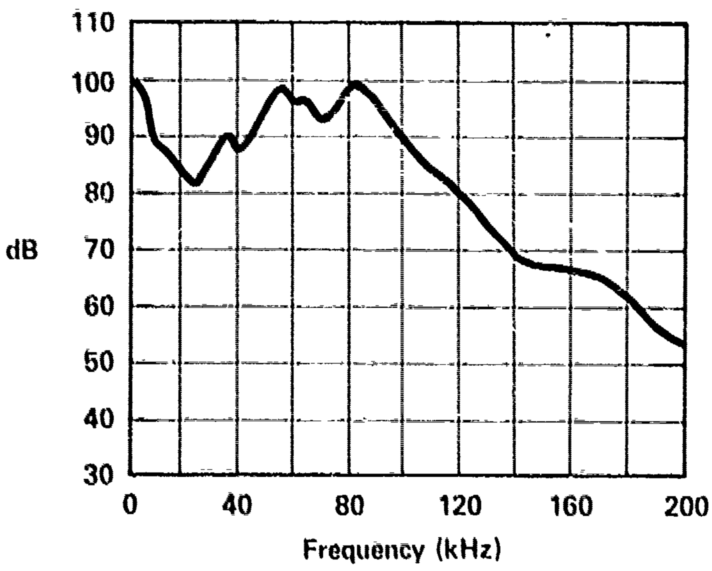
RELIEF VALVE – REPUBLIC RG70
INLET PRESSURE – 1750 PSI
RETURN PRESSURE – 750 PSI
FLOW TO VALVE – 10 GPM
B-408



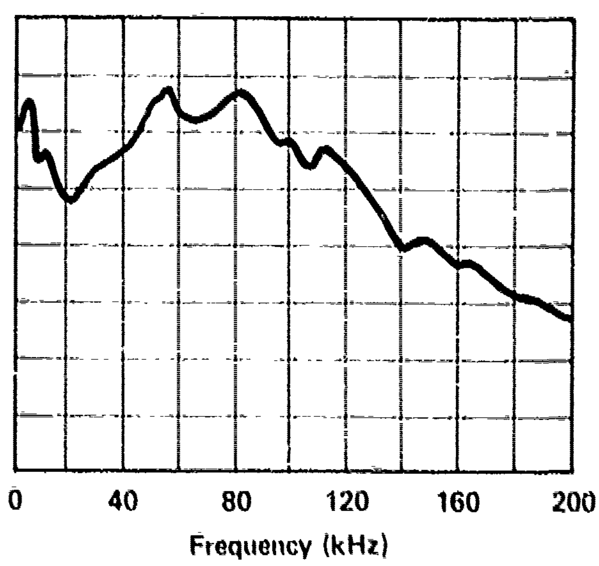
RELIEF VALVE – CIRCLE SEAL P10-776
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 9 GPM
B-501



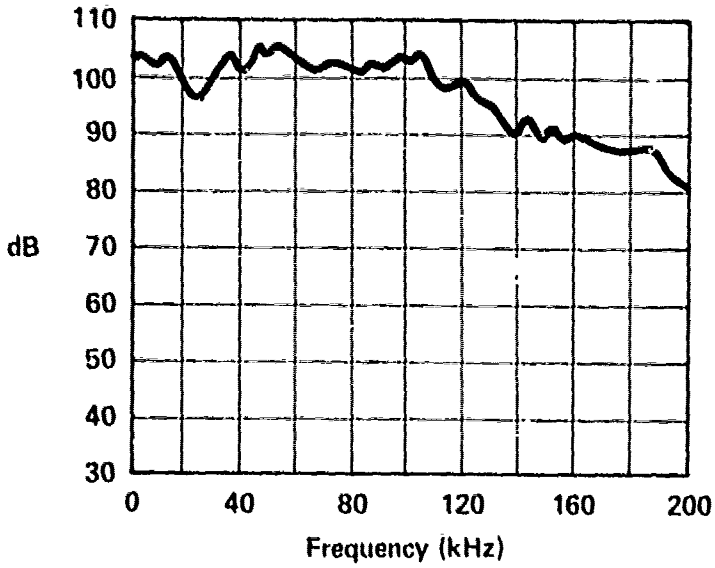
RELIEF VALVE – CIRCLE SEAL P10-776
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 9 GPM
B-502



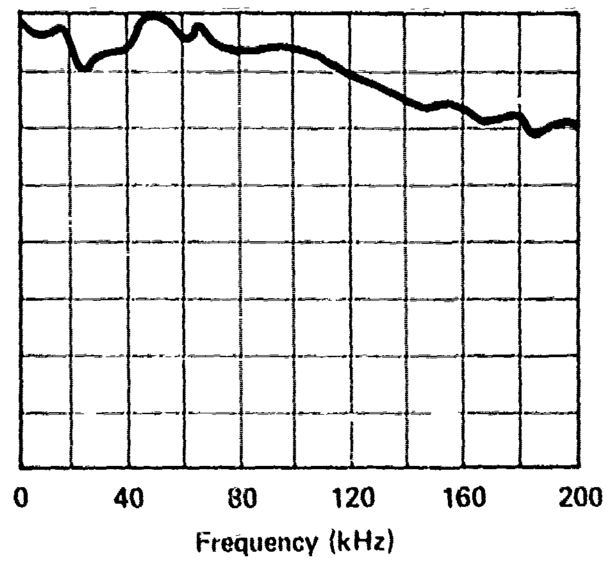
RELIEF VALVE – CIRCLE SEAL P10-776
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 9 GPM
B-503



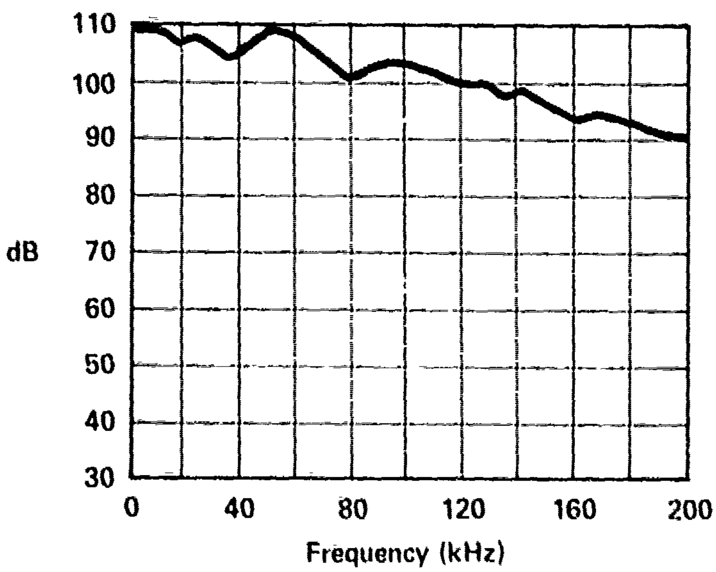
RELIEF VALVE – CIRCLE SEAL P10-776
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 1000 PSI
FLOW TO VALVE – 9 GPM
B-504



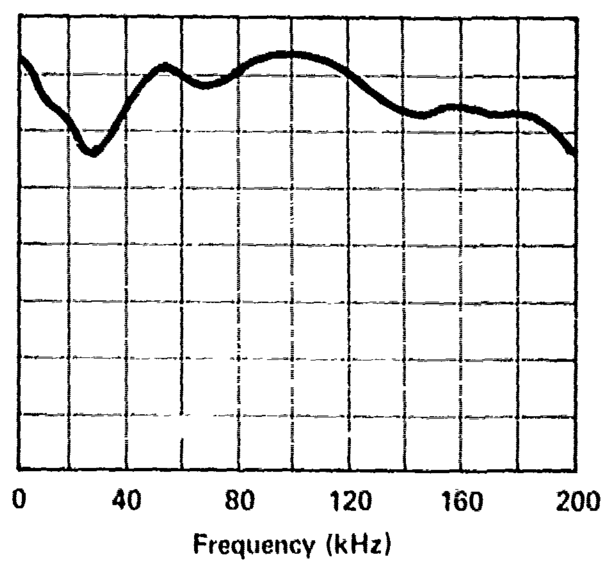
RELIEF VALVE – CIRCLE SEAL P10-776
INLET PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 9 GPM
B-505



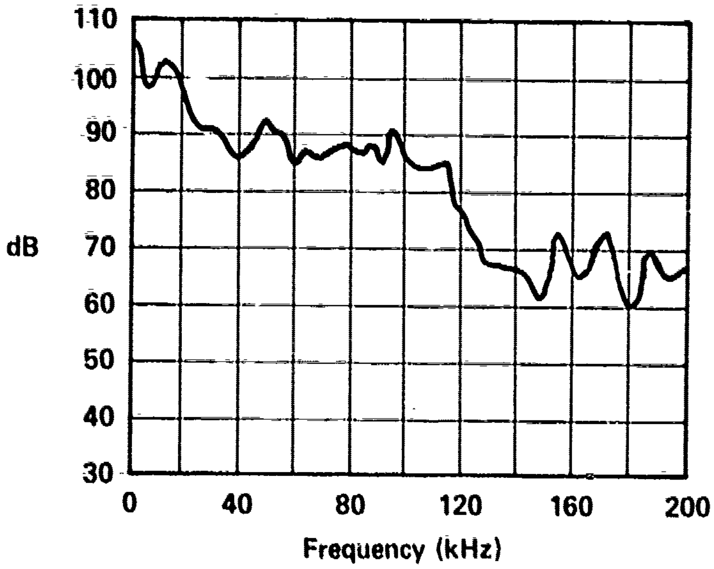
RELIEF VALVE – CIRCLE SEAL P10-776
INLET PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 18 GPM
B-506



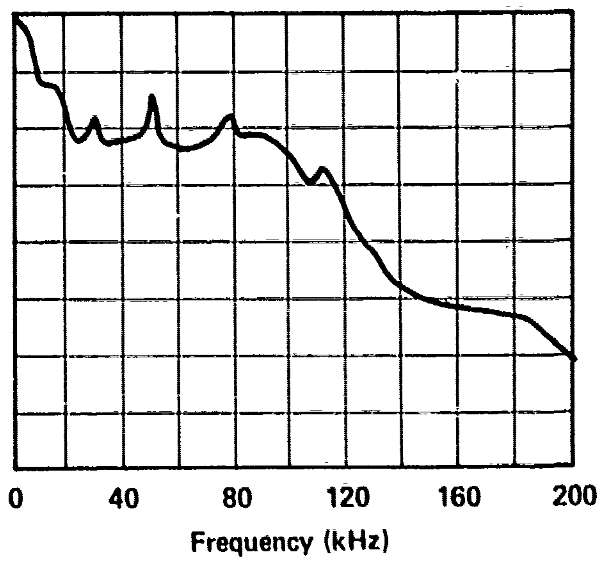
RELIEF VALVE – CIRCLE SEAL P10-776
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 18 GPM
B-507



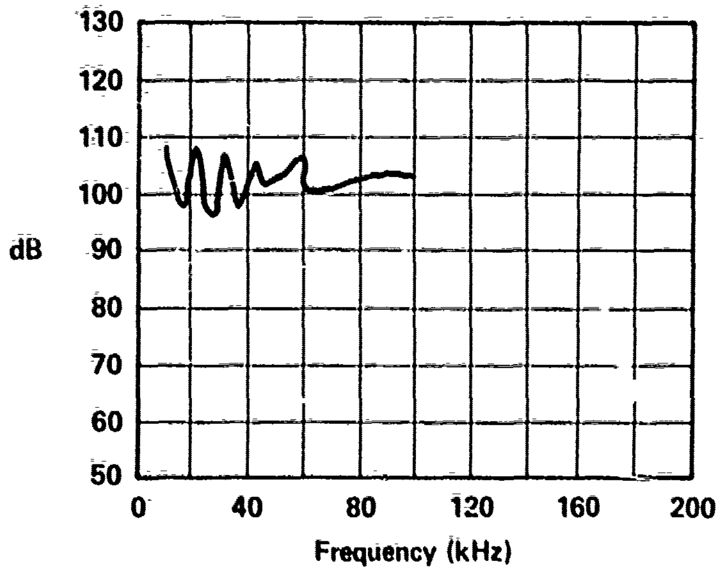
RELIEF VALVE – CIRCLE SEAL P10-776
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 18 GPM
B-508



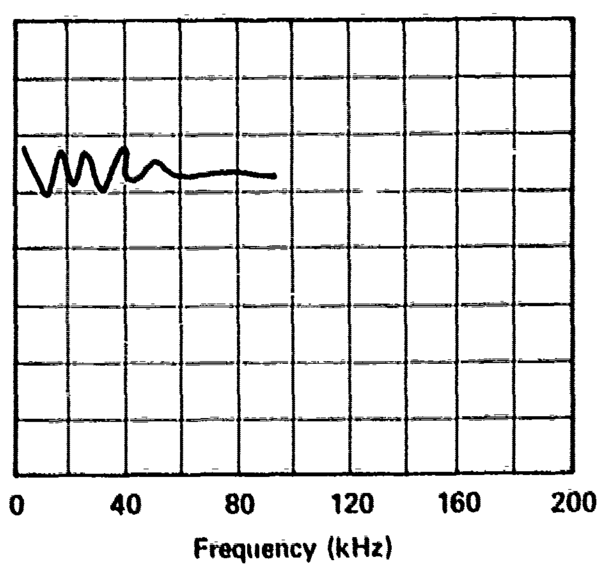
RELIEF VALVE – CIRCLE SEAL P10-776
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 18 GPM
B-509



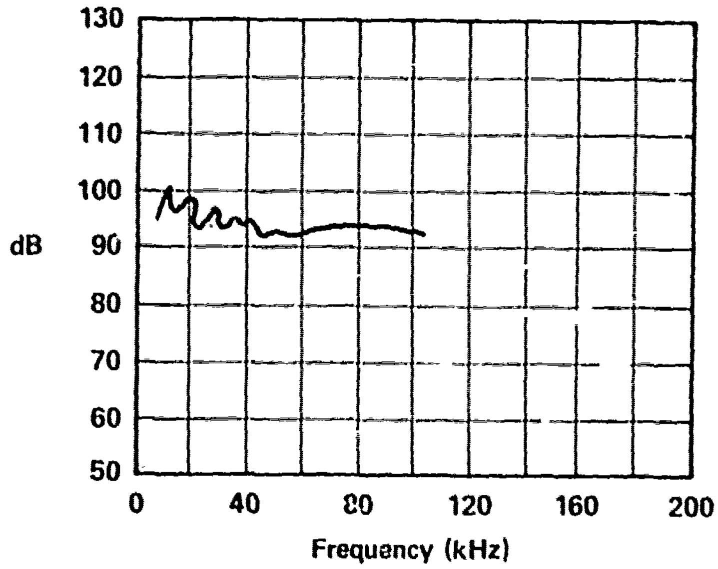
RELIEF VALVE – CIRCLE SEAL P10-776
INLET PRESSURE – 1500 PSI
RETURN PRESSURE – 1000 PSI
FLOW TO VALVE – 18 GPM
B-510



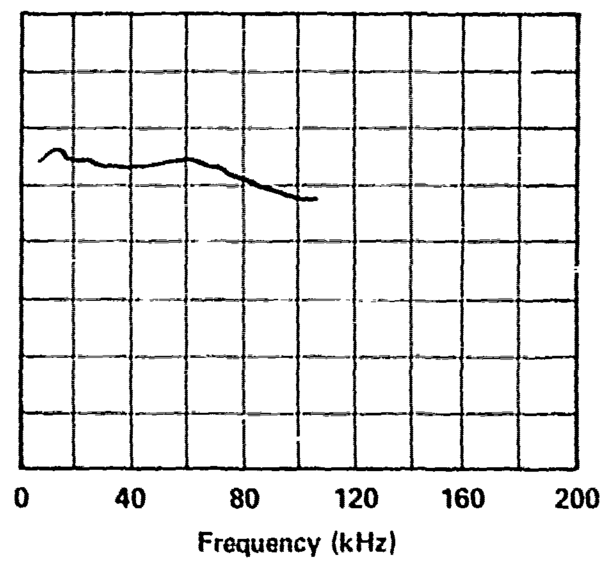
MOTOR – CHAR-LYNN
MOTOR RPM – 300 RPM
DISK DIAMETER – 22.625 IN
TESTED AT KU TREE RESERVOIR
C-101



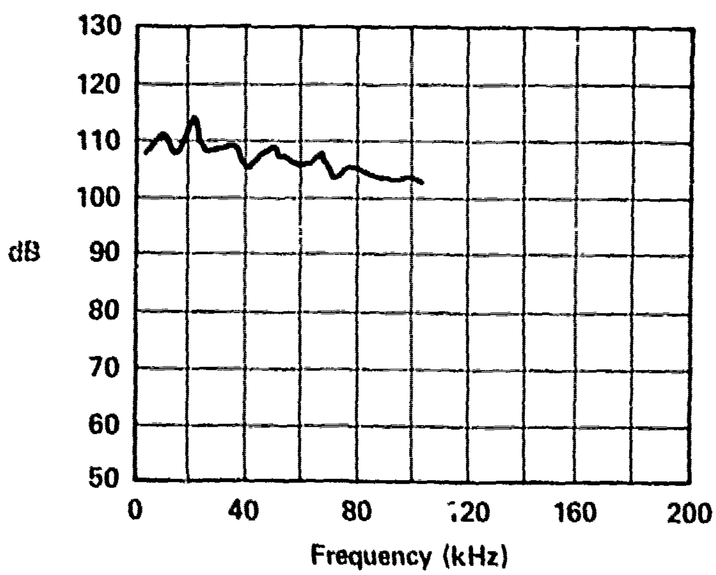
MOTOR – CHAR-LYNN
MOTOR RPM – 600 RPM
DISK DIAMETER – 22.625 IN
TESTED AT KU TREE RESERVOIR
C-102



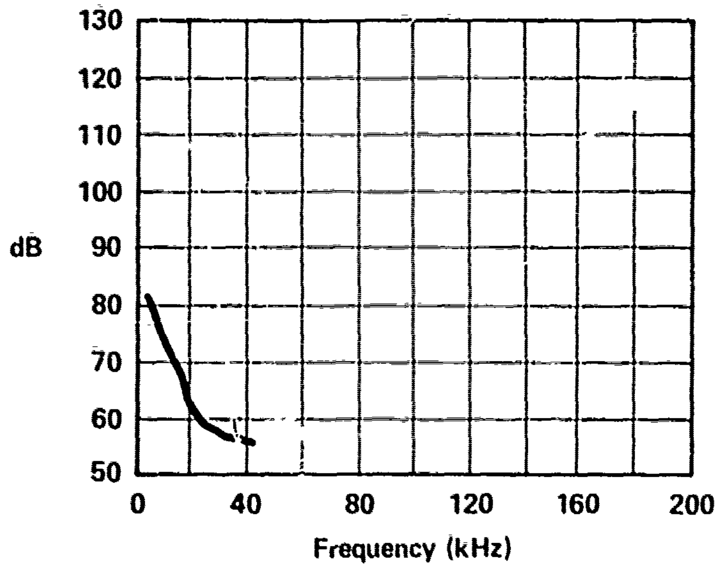
MOTOR – LAMINA
MOTOR RPM – 300 RPM
DISK DIAMETER – 22.625 IN
TESTED AT KU TREE RESERVOIR
C-201



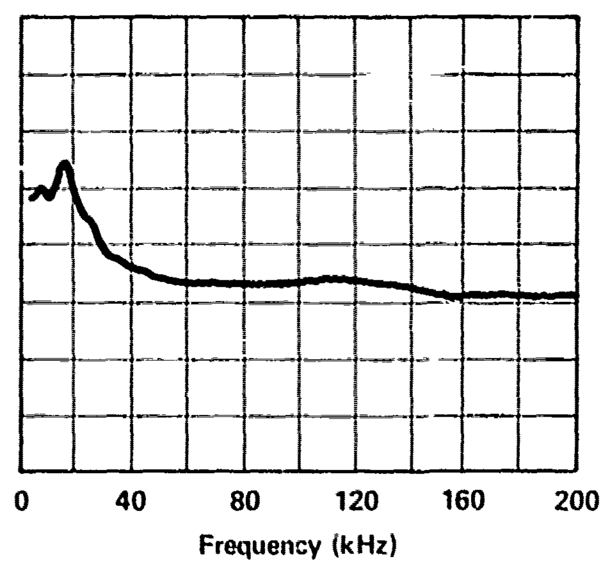
MOTOR – LAMINA
MOTOR RPM – 450 RPM
DISK DIAMETER – 22.625 IN
TESTED AT KU TREE RESERVOIR
C-202



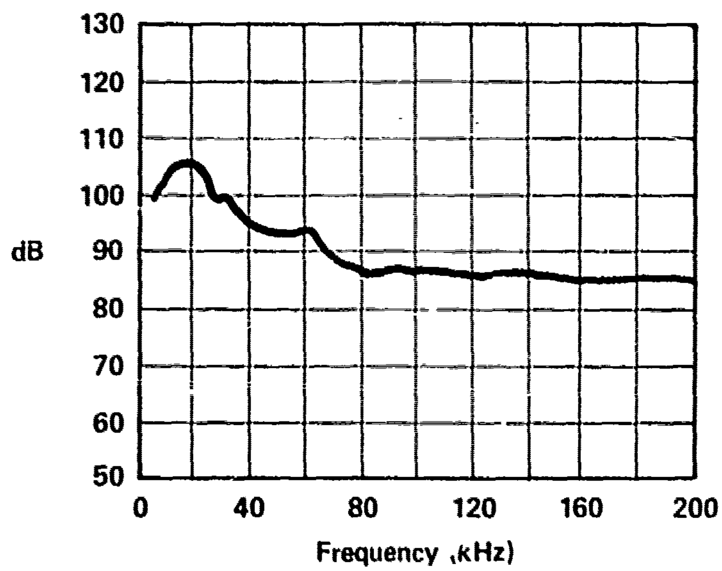
MOTOR – LAMINA
MOTOR RPM – 600 RPM
DISK DIAMETER – 22.625 IN
TESTED AT KU TREE RESERVOIR
C-203



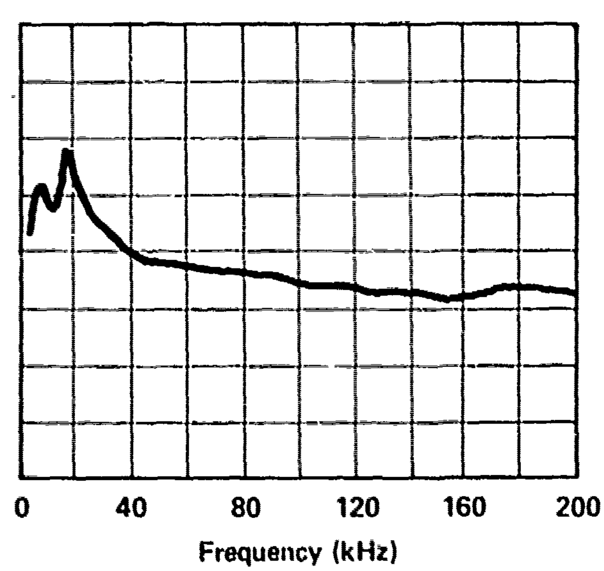
MOTOR – PLANET
MOTOR RPM – 300 RPM
DISK DIAMETER – 22.625 IN
TESTED AT LI TREE RESERVIOR
C-301



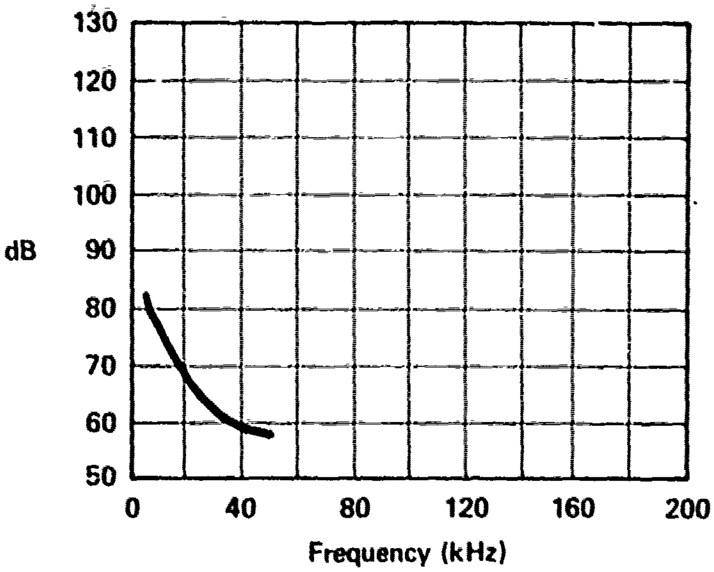
MOTOR – PLANET
MOTOR RPM – 450 RPM
DISK DIAMETER – 22.625 IN
TESTED AT KU TREE RESERVOIR
C-302



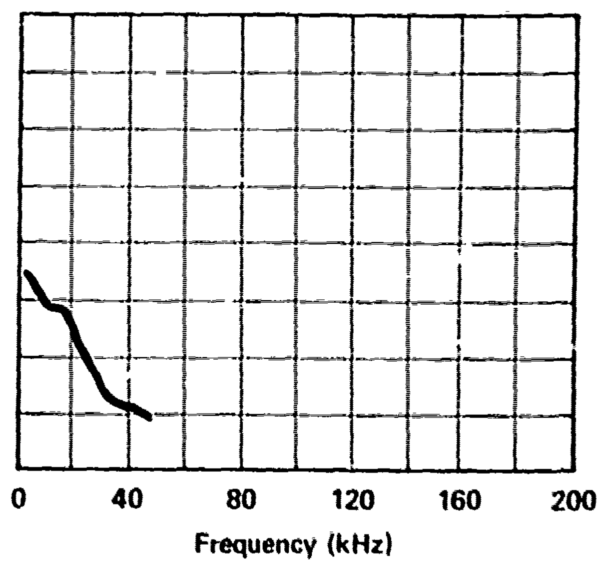
MOTOR – PLANET
MOTOR RPM – 600 RPM
DISK DIAMETER – 22.625 IN
TESTED AT KU TREE RESERVOIR
C-303



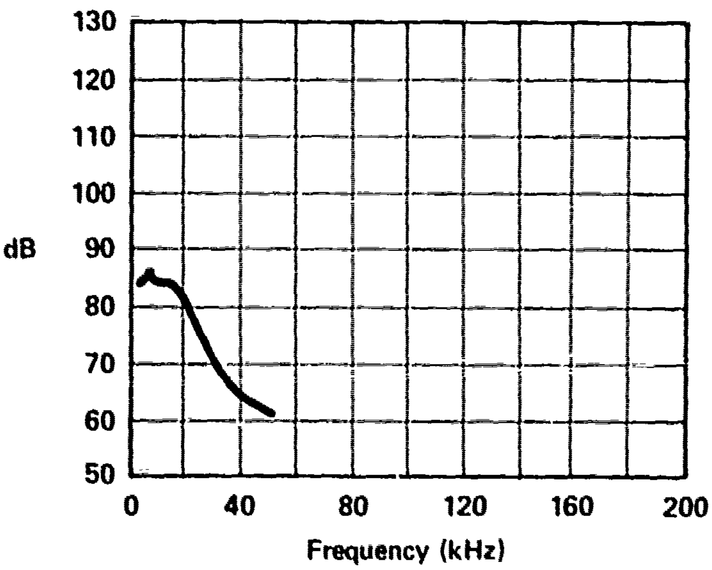
MOTOR – PLANET
MOTOR RPM – 900 RPM
DISK DIAMETER – 22.625 IN
TESTED AT KU TREE RESERVOIR
C-304



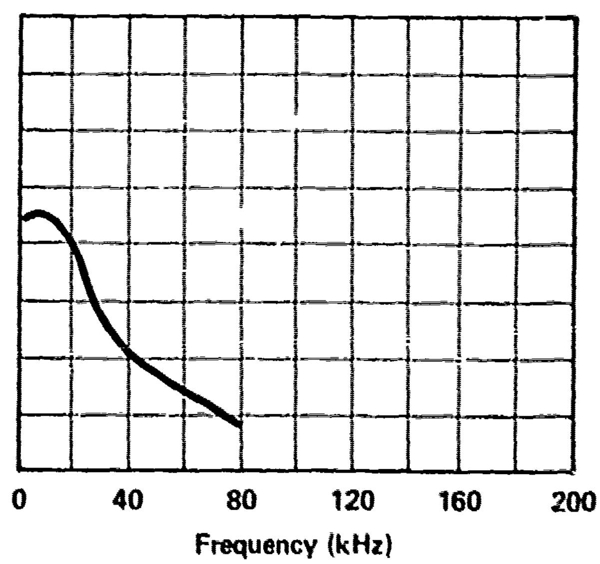
MOTOR – WSI
MOTOR RPM – 300 RPM
DISK DIAMETER – 22.625 IN
TESTED AT KU TREE RESERVOIR
C-401



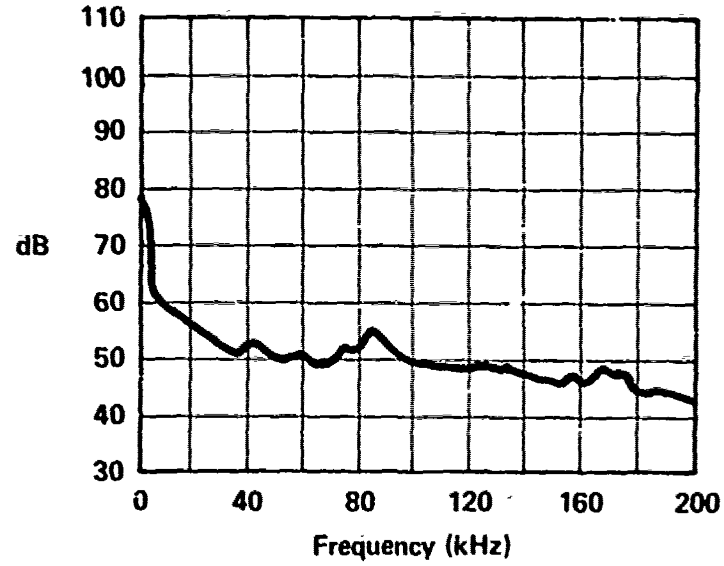
MOTOR – WSI
MOTOR – 450 RPM
DISK DIAMETER – 22.625 IN
TESTED AT KU TREE RESERVOIR
C-402



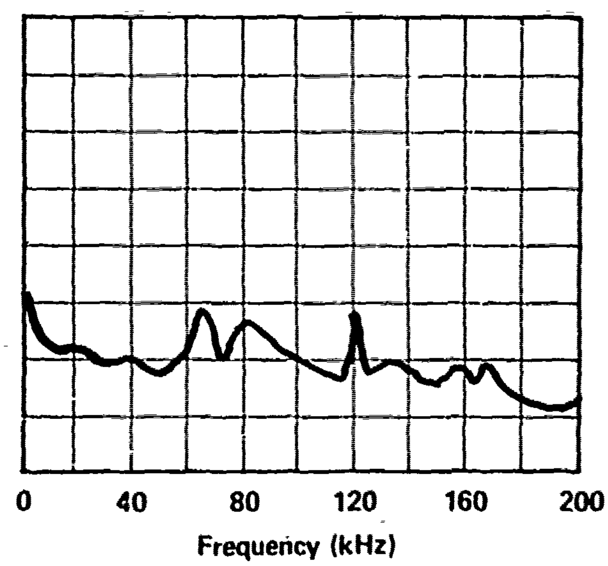
MOTOR – WSI
MOTOR RPM – 600 RPM
DISK DIAMETER – 22.625 IN
TESTED AT KU TREE RESERVOIR
C-403



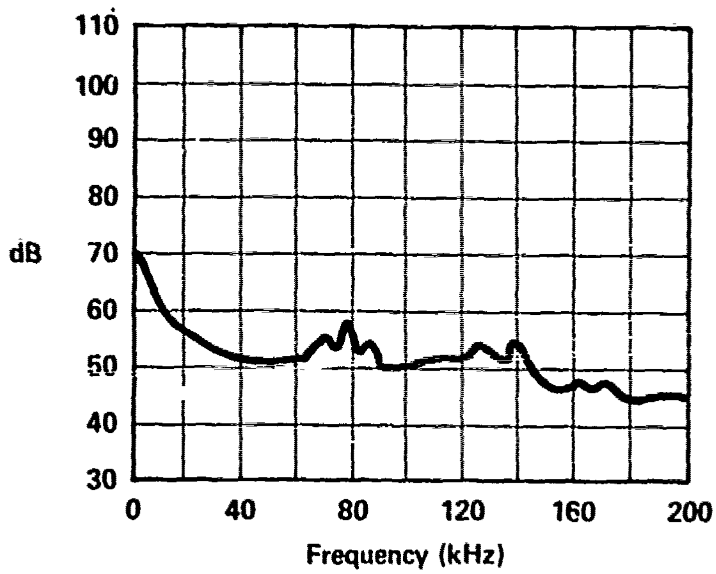
MOTOR – WSI
MOTOR RPM – 900 RPM
DISK DIAMETER – 22.625 IN
TESTED AT KU TREE RESERVOIR
C-404



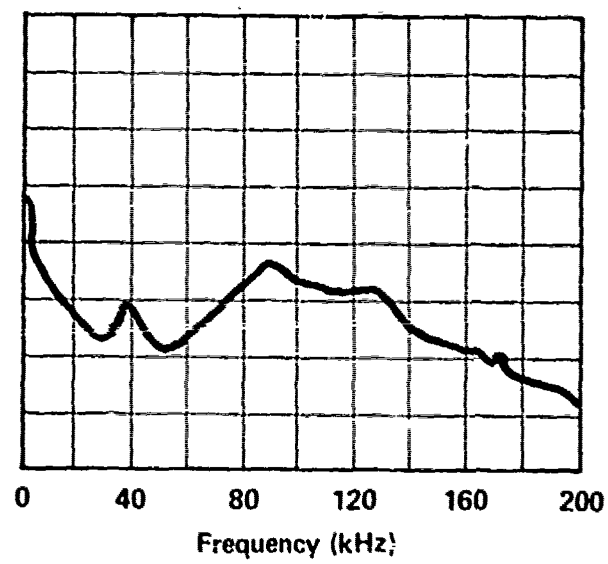
MOTOR – WSI
INLET PRESSURE – 100 PSI
RETURN PRESSURE – 0 PSI
FLOW TO MOTOR – 1 GPM
SHAFT RPM – 200 RPM
TORQUE PRODUCED – 80 IN-LB
DISK DIAMETER – 24 IN
C-405



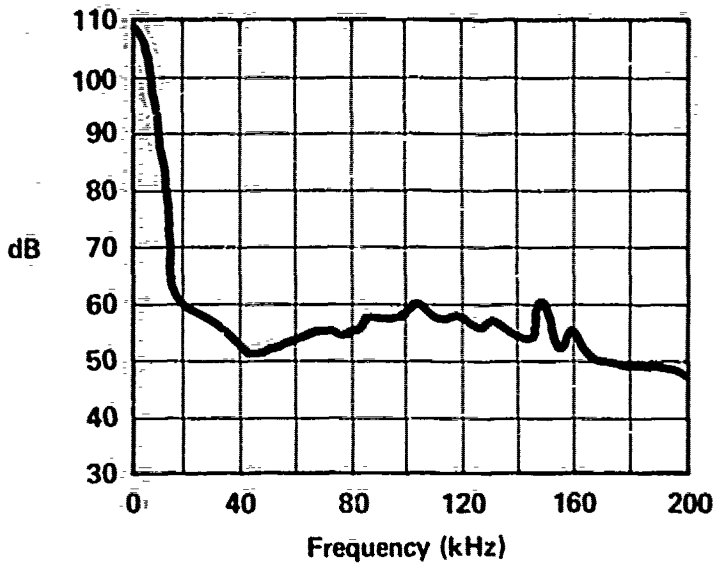
MOTOR – WSI
INLET PRESSURE – 300 PSI
RETURN PRESSURE – 100 PSI
FLOW TO MOTOR – 5 GPM
SHAFT RPM – 300 RPM
TORQUE PRODUCED – 120 IN-LB
DISK DIAMETER – 24 IN
C-406



MOTOR – WSI
INLET PRESSURE – 500 PSI
RETURN PRESSURE – 150 PSI
FLOW TO MOTOR – 7.1 GPM
SHAFT RPM – 450 RPM
TORQUE PRODUCED – 220 IN-LB
DISK DIAMETER – 24 IN
C-407



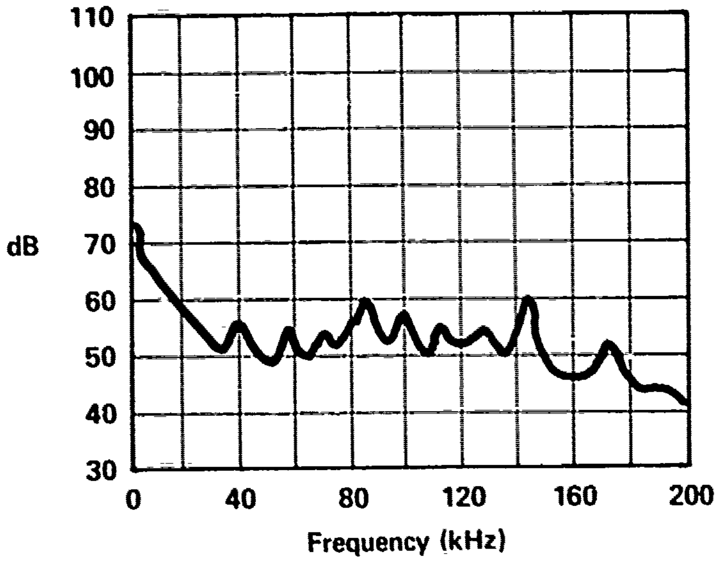
MOTOR – WSI
INLET PRESSURE – 800 PSI
RETURN PRESSURE – 150 PSI
FLOW TO MOTOR – 10 GPM
SHAFT RPM – 600 RPM
TORQUE PRODUCED – 400 IN-LB
DISK DIAMETER – 24 IN
C-408



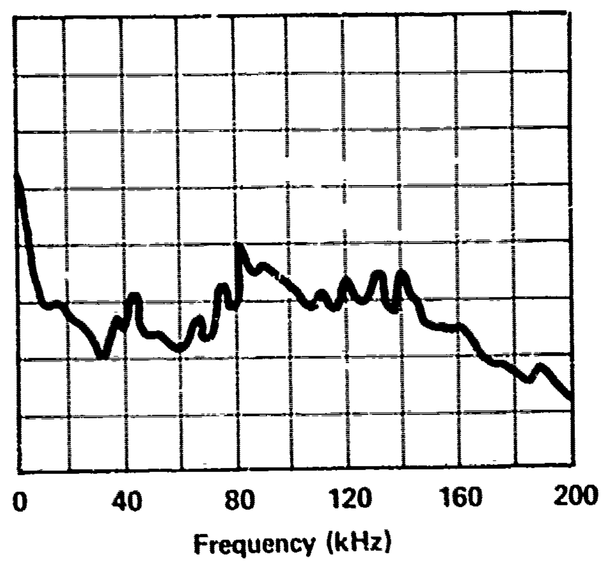
MOTOR – WSI

INLET PRESSURE –	500 PSI
RETURN PRESSURE –	150 PSI
FLOW TO MOTOR –	5 GPM
SHAFT RPM –	300 RPM
TORQUE PRODUCED –	200 IN-LB
DISK DIAMETER –	28 IN

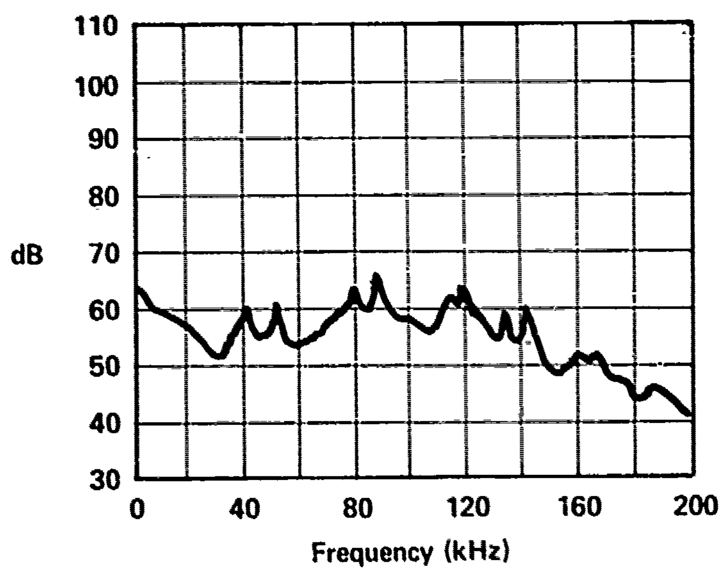
C-409



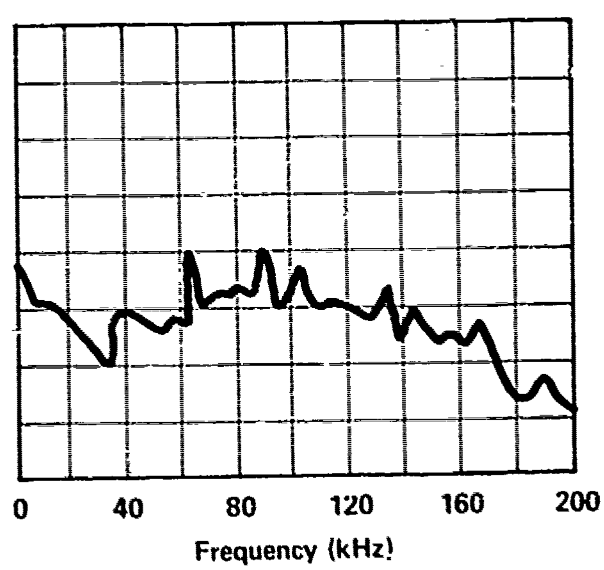
MOTOR – WSI
INLET PRESSURE – 250 PSI
RETURN PRESSURE – 125 PSI
FLOW TO MOTOR – 2.5 GPM
SHAFT RPM – 150 RPM
TORQUE PRODUCED – 100 IN-LB
DISK DIAMETER – 32.875 IN
C-410



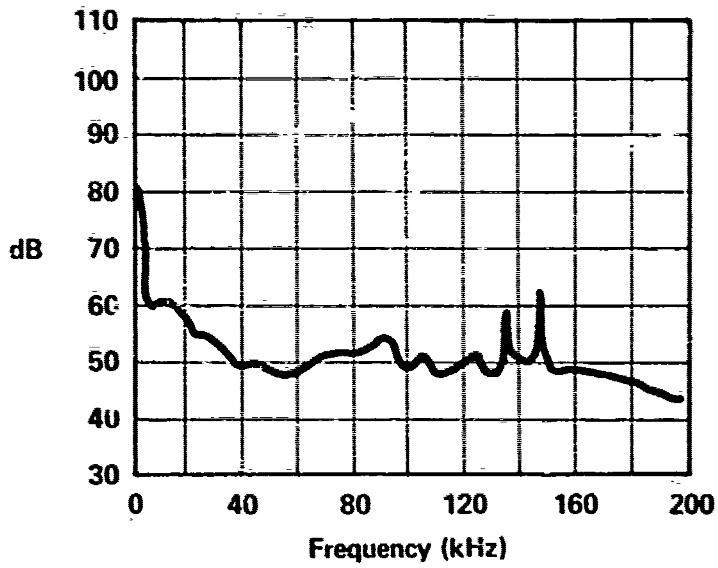
MOTOR – WSI
INLET PRESSURE – 750 PSI
RETURN PRESSURE – 125 PSI
FLOW TO MOTOR – 5 GPM
SHAFT RPM – 300 RPM
TORQUE PRODUCED – 340 IN-LB
DISK DIAMETER – 32.875 IN
C-411



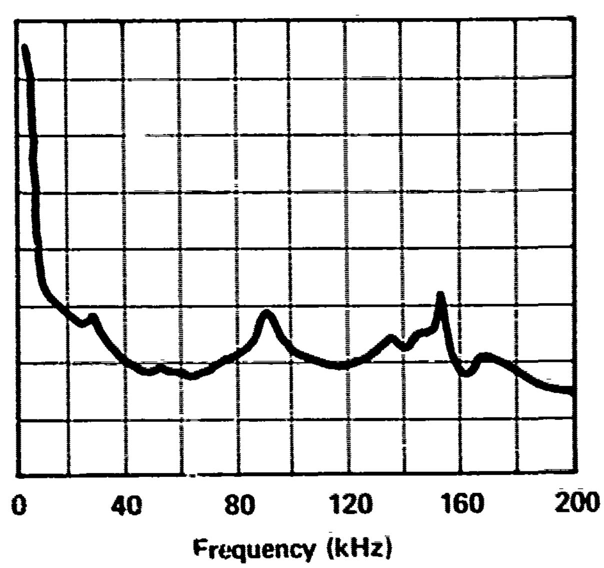
MOTOR – WSI
INLET PRESSURE – 800 PSI
RETURN PRESSURE – 125 PSI
FLOW TO MOTOR – 5.6 GPM
SHAFT RPM – 324 RPM
TORQUE PRODUCED – 420 IN-LB
DISK DIAMETER – 32.875 IN
C-412



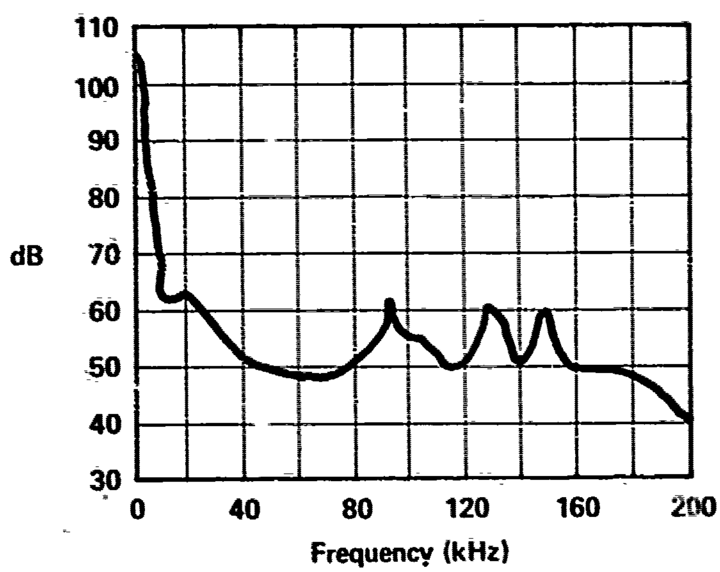
MOTOR – WSI
INLET PRESSURE – 1000 PSI
RETURN PRESSURE – 125 PSI
FLOW TO MOTOR – 6.5 GPM
SHAFT RPM – 342 RPM
TORQUE PRODUCED – 510 IN-LB
DISK DIAMETER – 32.875 IN
C-413



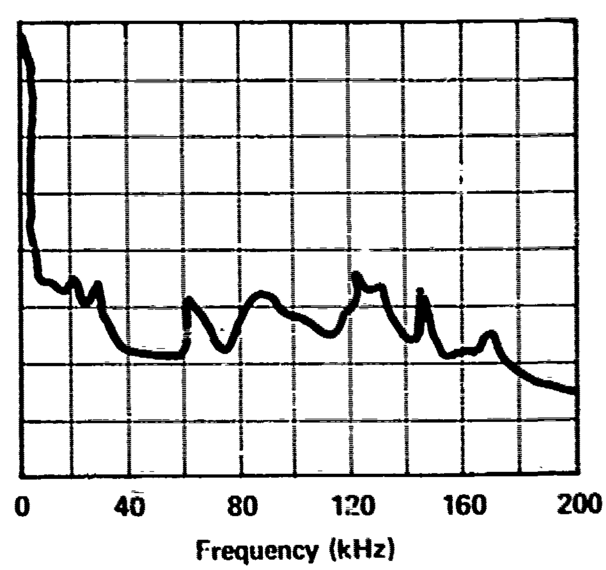
MOTOR – WSI
INLET PRESSURE – 400 PSI
RETURN PRESSURE – 125 PSI
FLOW TO MOTOR – 2.5 GPM
SHAFT RPM – 150 RPM
TORQUE PRODUCED – 220 IN-LB
DISK DIAMETER – 35.75 IN
C-414



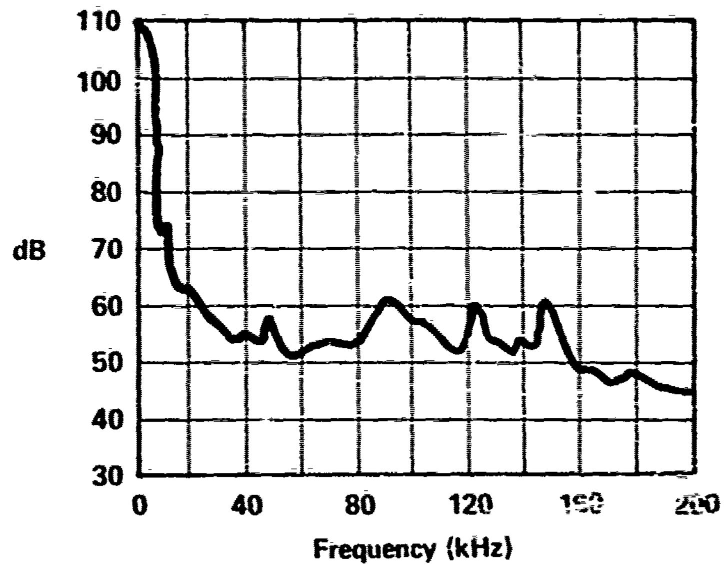
MOTOR – WSI
INLET PRESSURE – 600 PSI
RETURN PRESSURE – 125 PSI
FLOW TO MOTOR – 3.8 GPM
SHAFT RPM – 210 RPM
TORQUE PRODUCED – 320 IN-LB
DISK DIAMETER – 35.75 IN
C-415



MOTOR – WSI
INLET PRESSURE – 850 PSI
RETURN PRESSURE – 125 PSI
FLOW TO MOTOR – 4.8 GPM
SHAFT RPM – 260 RPM
TORQUE PRODUCED – 510 IN-LB
DISK DIAMETER – 35.75 IN
C-416

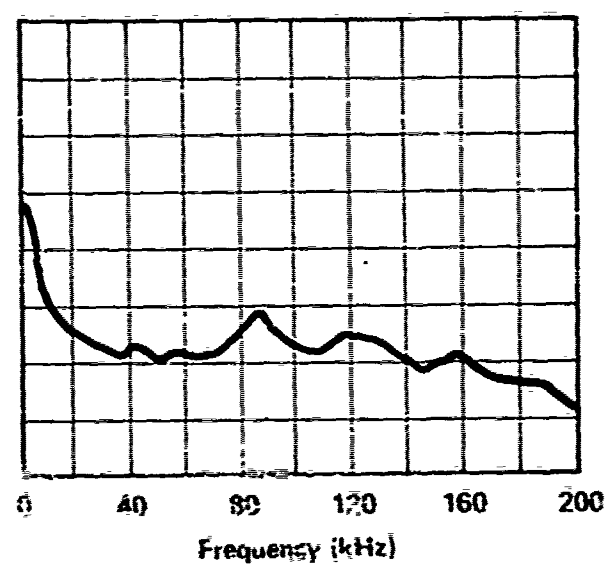


MOTOR – WSI
INLET PRESSURE – 1100 PSI
RETURN PRESSURE – 125 PSI
FLOW TO MOTOR – 5 GPM
SHAFT RPM – 300 RPM
TORQUE PRODUCED – 600 IN-LB
DISK DIAMETER – 35.75 IN
C-417



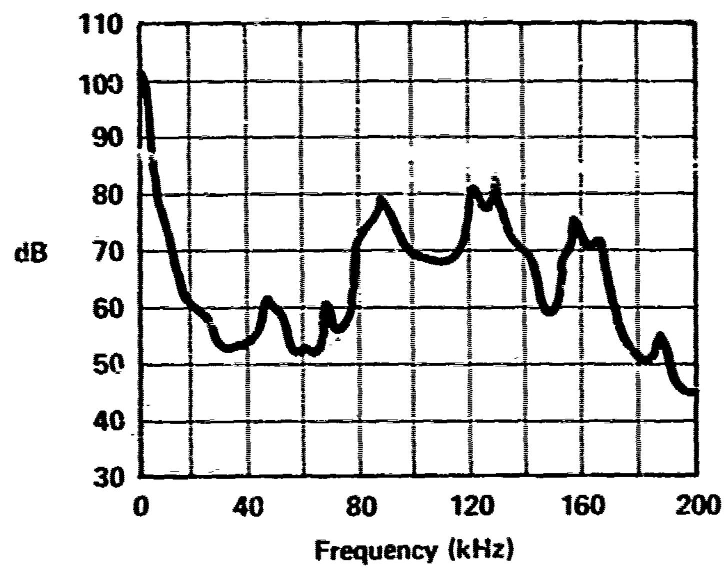
MOTOR – NUTRON
INLET PRESSURE – [illegible]
RETURN PRESSURE – 150 PSI
FLOW TO MOTOR – 2 GPM
SHAFT RPM – 192 RPM
TORQUE PRODUCED – 40 IN-LB
DISK DIAMETER – 24 IN

C-501



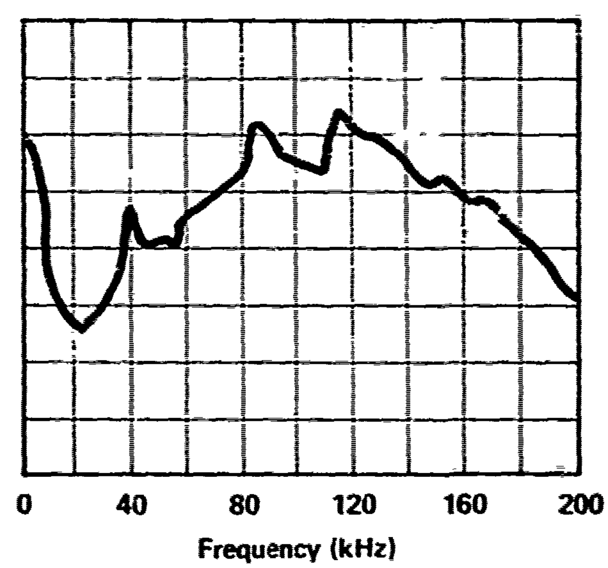
MOTOR – NUTRON
INLET PRESSURE – 500 PSI
RETURN PRESSURE – 150 PSI
FLOW TO MOTOR – 3 GPM
SHAFT RPM – 288 RPM
TORQUE PRODUCED – 100 IN-LB
DISK DIAMETER – 24 IN

C-502



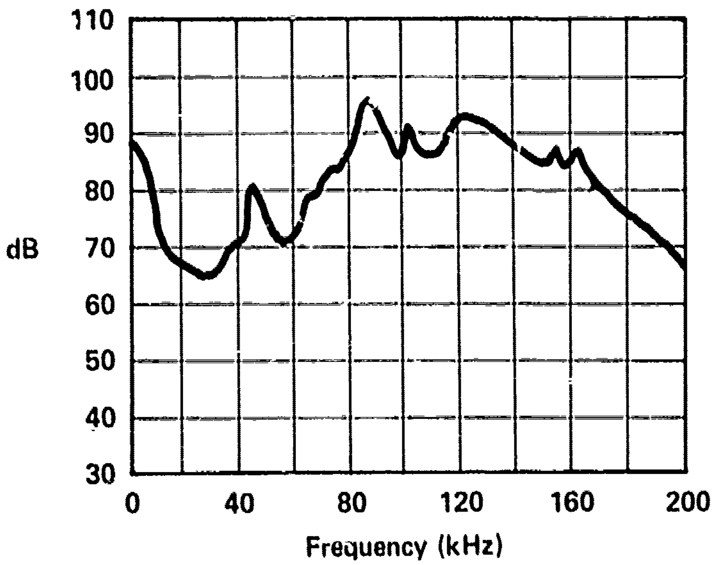
MOTOR – NUTRON
INLET PRESSURE – 850 PSI
RETURN PRESSURE – 150 PSI
FLOW TO MOTOR – 4.5 GPM
SHAFT RPM – 432 RPM
TORQUE PRODUCED – 200 IN-LB
DISK DIAMETER – 24 IN

C-503



MOTOR – NUTRON
INLET PRESSURE – 1150 PSI
RETURN PRESSURE – 150 PSI
FLOW TO MOTOR – 6 GPM
SHAFT RPM – 552 RPM
TORQUE PRODUCED – 390 IN-LB
DISK DIAMETER – 24 IN

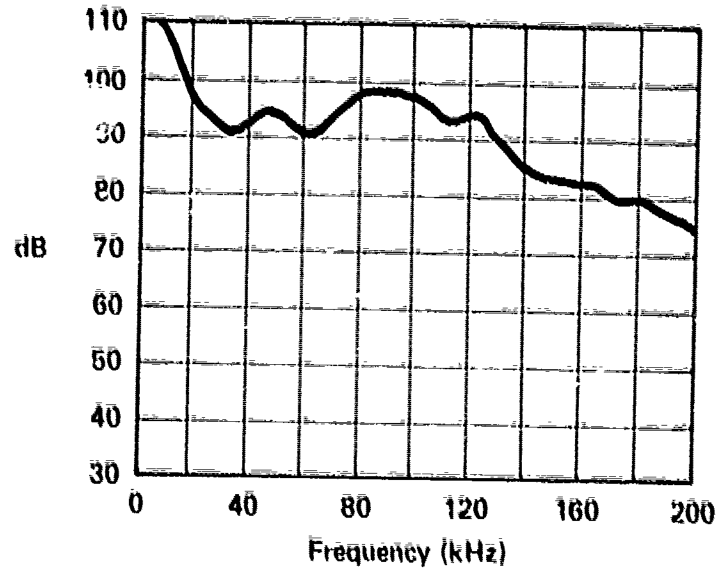
C-504



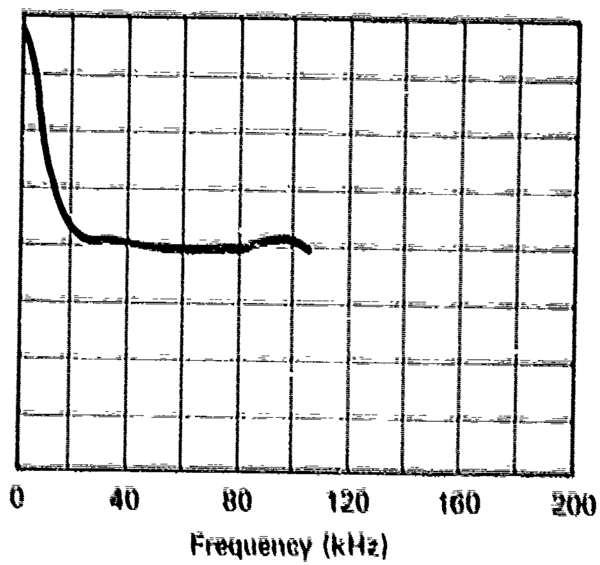
MOTOR – NUTRON

INLET PRESSURE –	1300 PSI
RETURN PRESSURE –	150 PSI
FLOW TO MOTOR –	6.6 GPM
SHAFT RPM –	600 RPM
TORQUE PRODUCED –	400 IN-LB
DISK DIAMETER –	24 IN

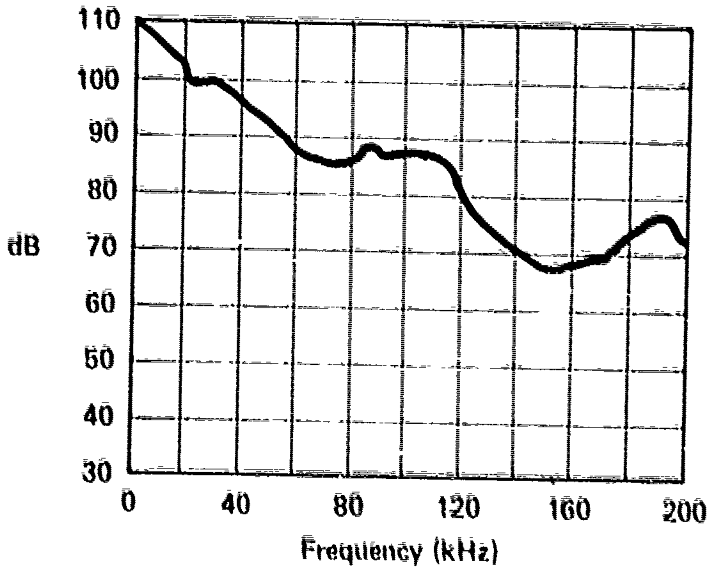
C-505



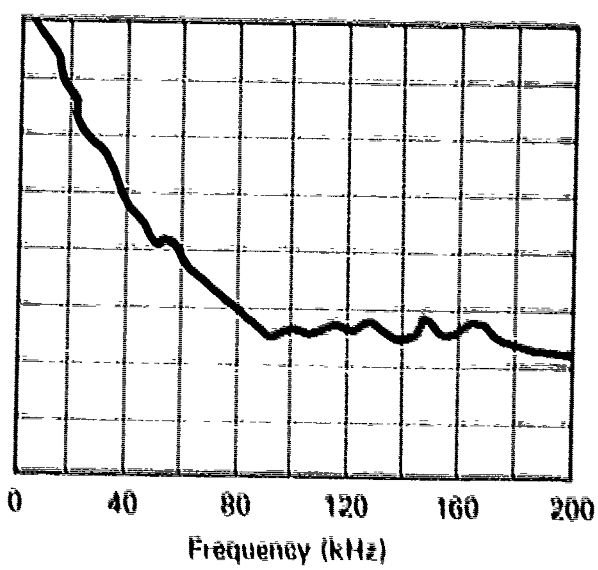
PUMP – VICKERS V30-15
OUTPUT PRESSURE – 1000 PSI
OUTPUT FLOW – 20 GPM
DRIVE MOTOR – GE MOTOR @ 1750 RPM
DRIVE COUPLING – DELRIN DIRECT DRIVE
D-101



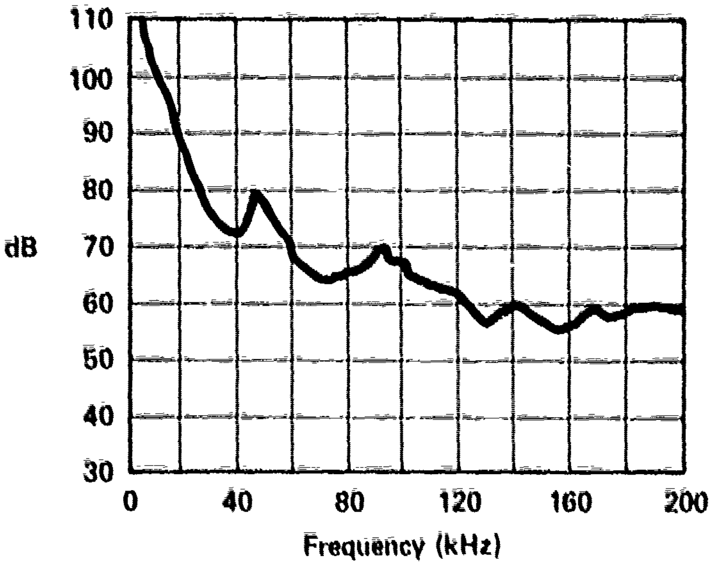
PUMP – VICKERS V30-15
OUTPUT PRESSURE – 1500 PSI
INLET PRESSURE – 500 PSI
OUTPUT FLOW – 20 GPM
DRIVE MOTOR – GE MOTOR @ 1750 RPM
DRIVE COUPLING – DELRIN DIRECT DRIVE
D-102



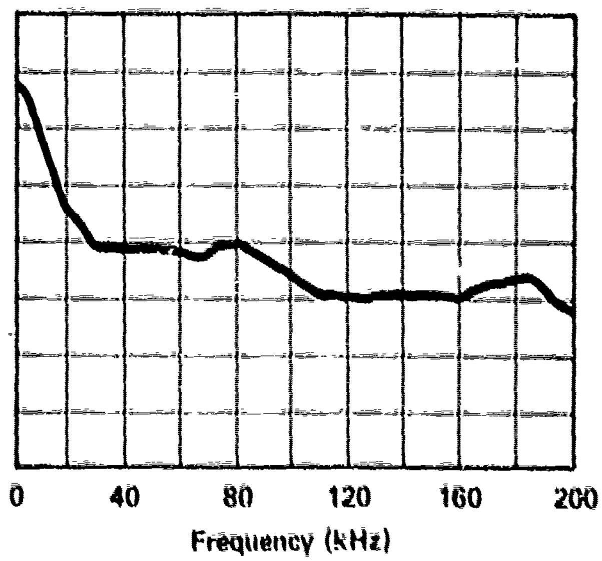
PUMP – BORG WARNER P4-2B
OUTPUT PRESSURE – 1000 PSI
OUTPUT FLOW – 24 GPM
DRIVE MOTOR – GE MOTOR @ 1750 RPM
DRIVE COUPLING – DELRIN DIRECT DRIVE
D-201



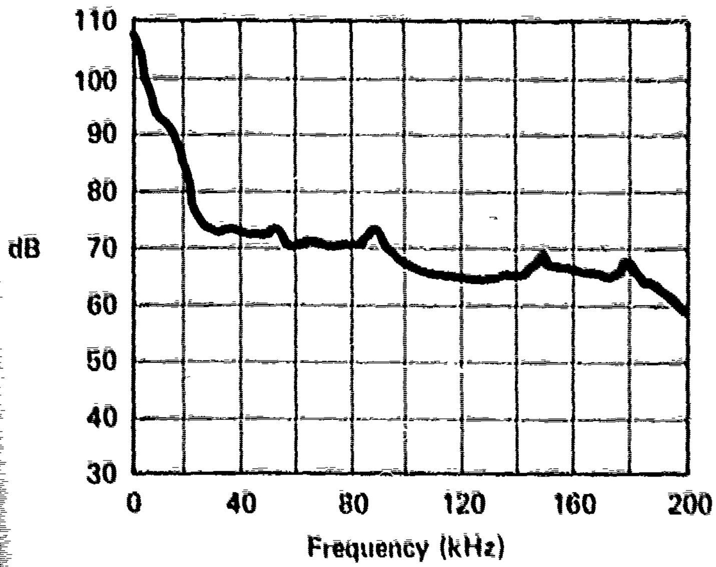
PUMP – DELAVAL IMO
OUTPUT PRESSURE – 1000 PSI
OUTPUT FLOW – 10 GPM
DRIVE MOTOR – GE MOTOR @ 1750 RPM
DRIVE COUPLING – DELRIN DIRECT DRIVE
D-301



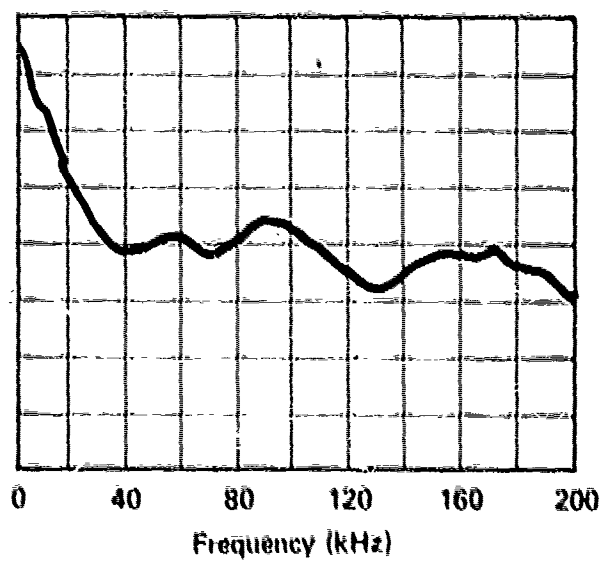
PUMP – RACINE SUPERVANE
OUTPUT PRESSURE – 1000 PSI
OUTPUT FLOW – 0 GPM
DRIVE MOTOR – GE MOTOR @ 1750 RPM
DRIVE COUPLING – DELRIN DIRECT DRIVE
D-401



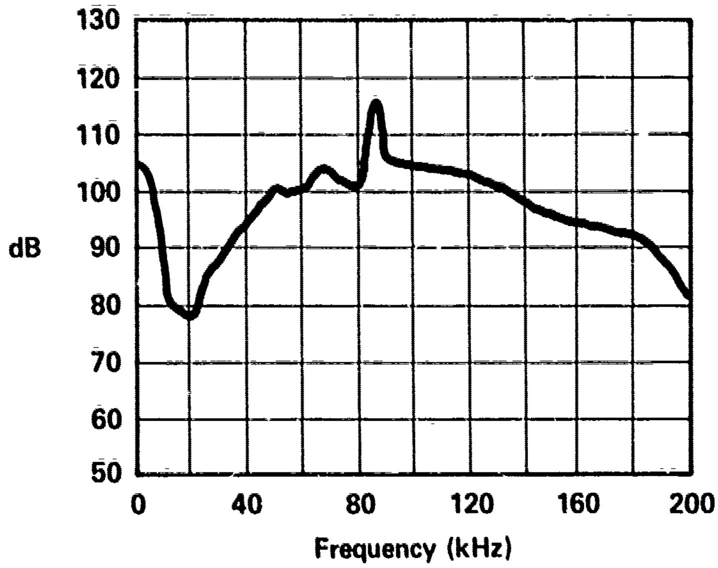
PUMP – RACINE SUPERVANE
OUTPUT PRESSURE – 1000 PSI
OUTPUT FLOW – 5 GPM
DRIVE MOTOR – GE MOTOR @ 1750 RPM
DRIVE COUPLING – DELRIN DIRECT DRIVE
D-402



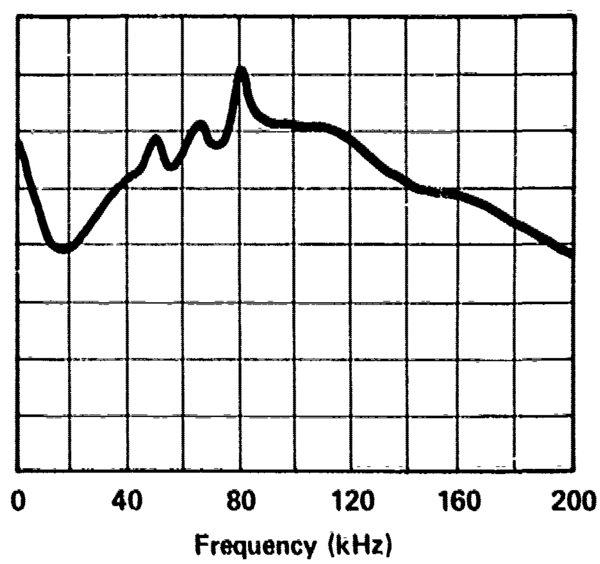
PUMP – RACINE SUPERVANE
OUTPUT PRESSURE – 1000 PSI
OUTPUT FLOW – 10 GPM
DRIVE MOTOR – GE MOTOR @ 1750 RPM
DRIVE COUPLING – DELRIN DIRECT DRIVE
D-403



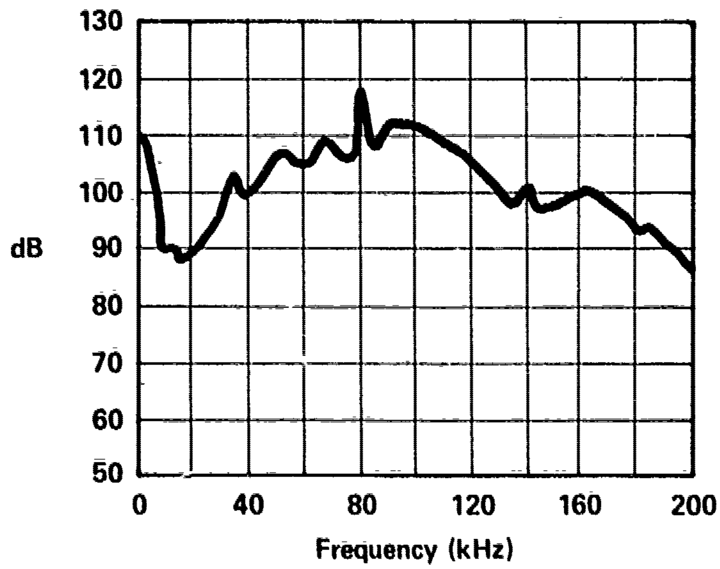
PUMP – RACINE SUPERVANE
OUTPUT PRESSURE – 1000 PSI
OUTPUT FLOW – 13 GPM
DRIVE MOTOR – GE MOTOR @ 1750 RPM
DRIVE COUPLING – DELRIN DIRECT DRIVE
D-404



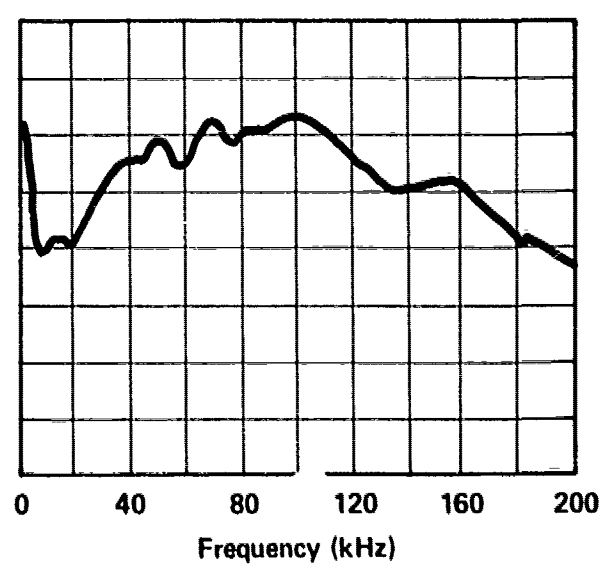
SERVO VALVE – MOOG 74
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 1.8 GPM
E-101



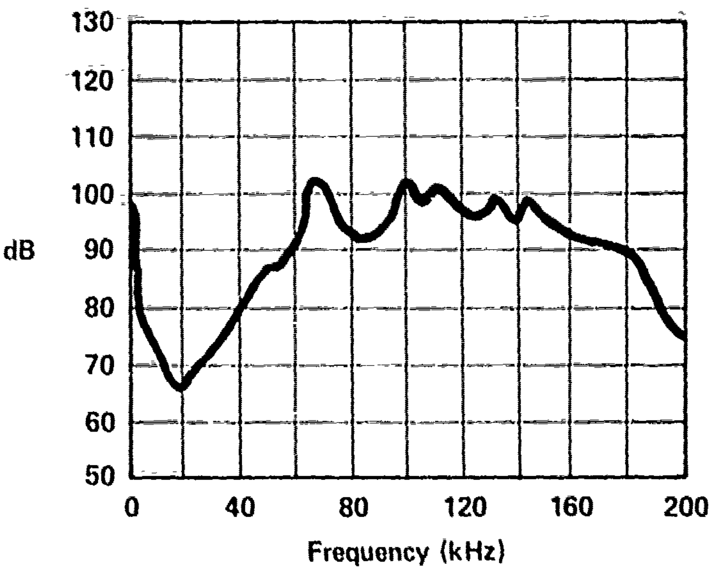
SERVO VALVE – MOOG 74
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 4.7 GPM
E-102



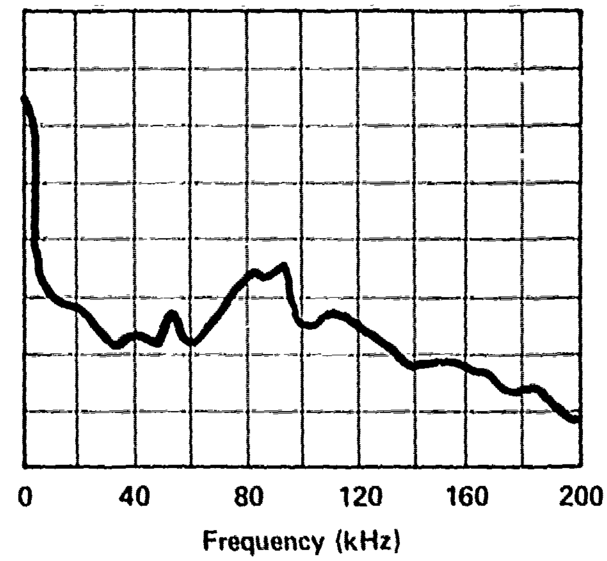
SERVO VALVE – MOOG 74
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 7.2 GPM
E-103



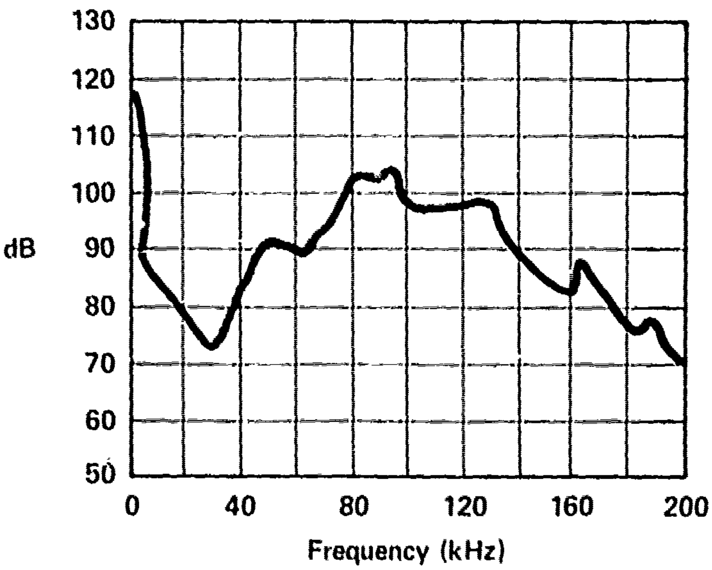
SERVO VALVE – MOOG 74
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 7.4 GPM
E-104



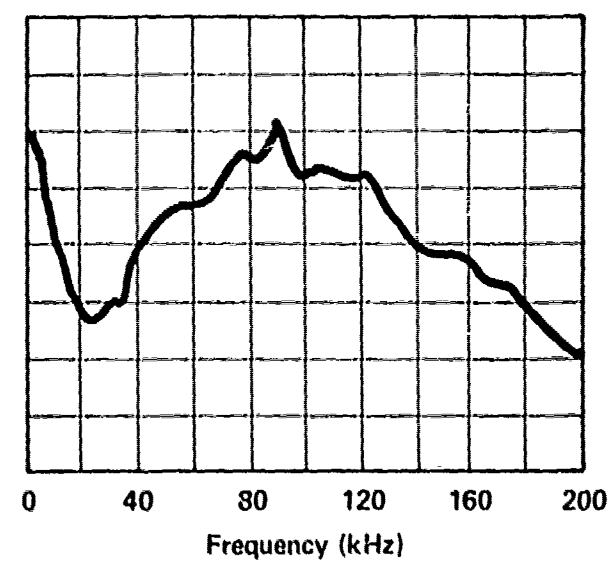
SERVO VALVE – MOOG 74
INLET PRESSURE – 1250 PSI
C_1/C_2 PRESSURE – 750 PSI
RETURN PRESSURE – 250 PSI
FLOW TO VALVE – 4 GPM
E-105



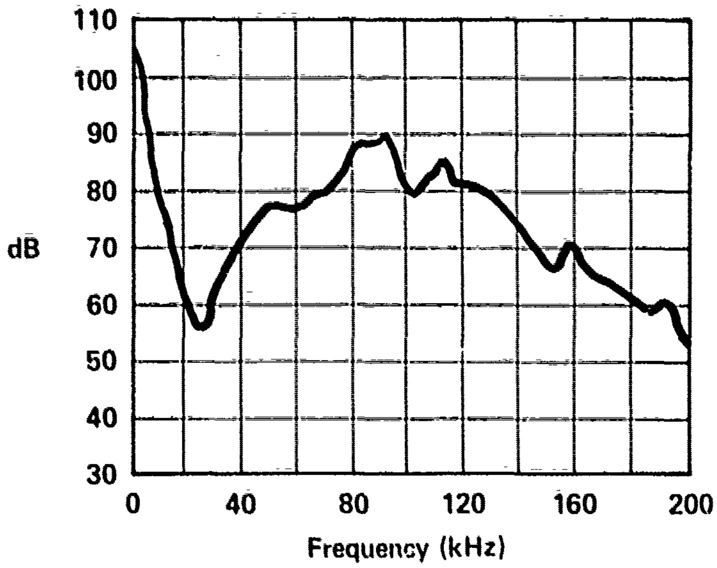
SERVO VALVE – MOOG 74
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 0 GPM
E-106



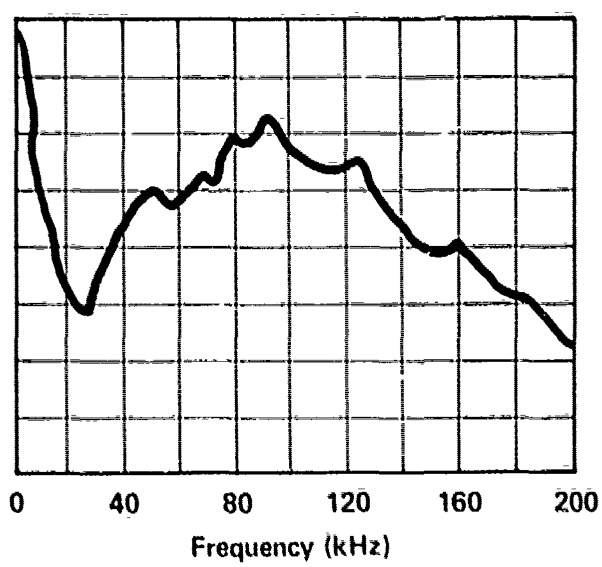
SERVO VALVE – MOOG 74
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 3.2 GPM
E-107



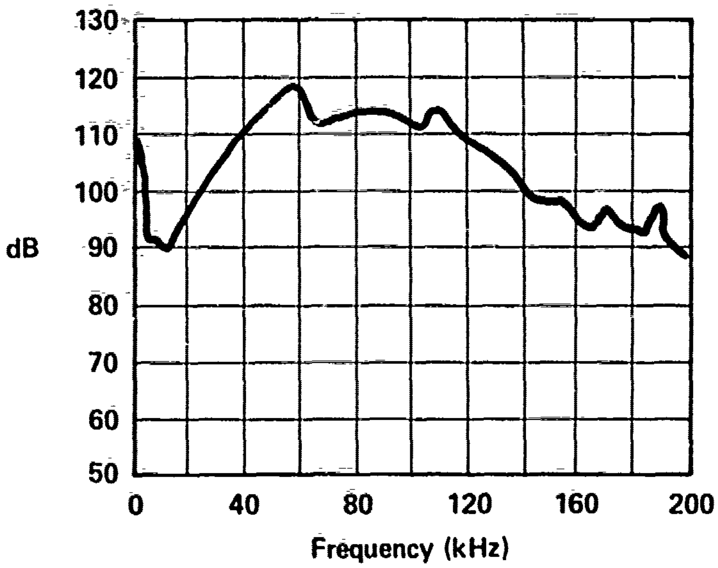
SERVO VALVE – MOOG 74
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 5.7 GPM
E-108



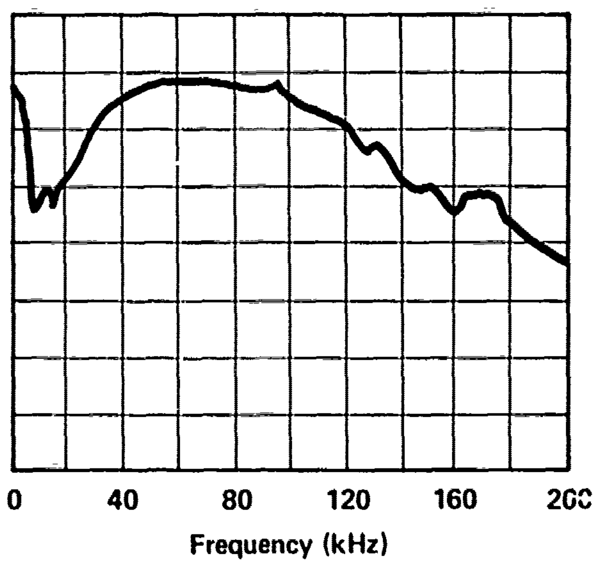
SERVO VALVE – MOOG 74
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 7.5 GPM
E-109



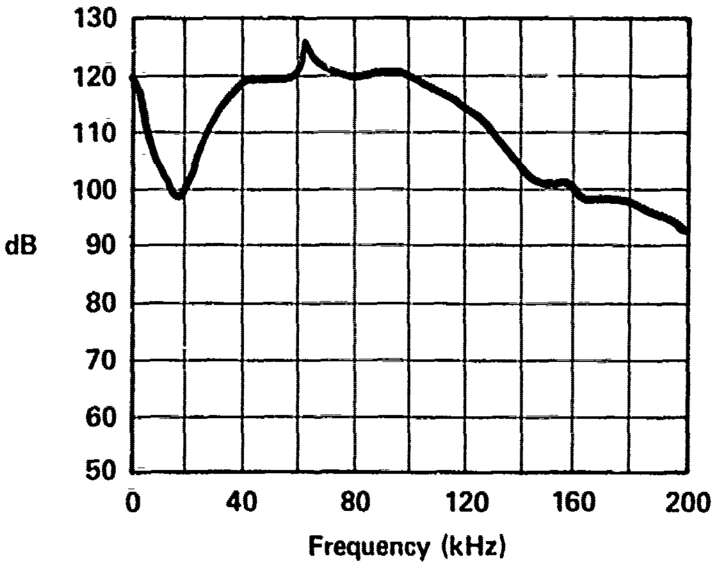
SERVO VALVE – MOOG 74
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 7.6 GPM
E-110



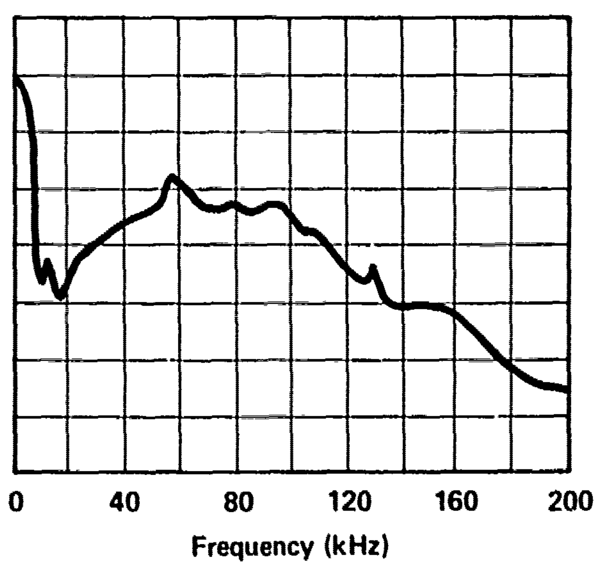
SERVO VALVE – MOOG 35
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 4 GPM
E-201



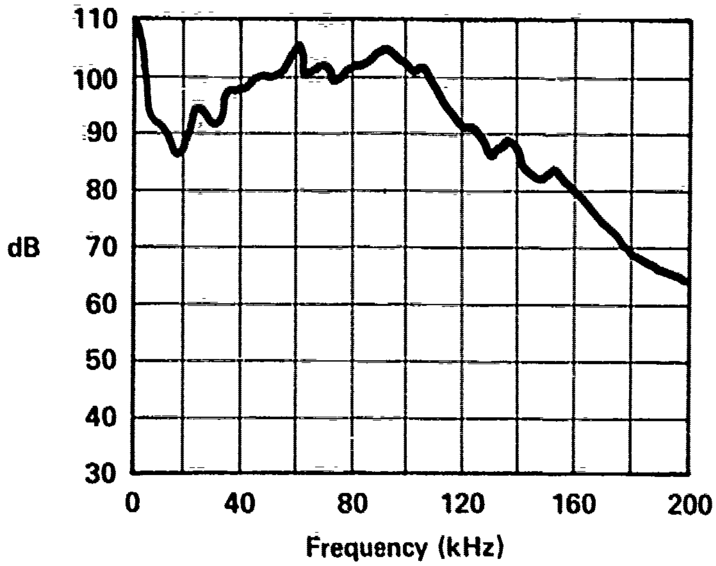
SERVO VALVE – MOOG 35
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 6 GPM
E-202



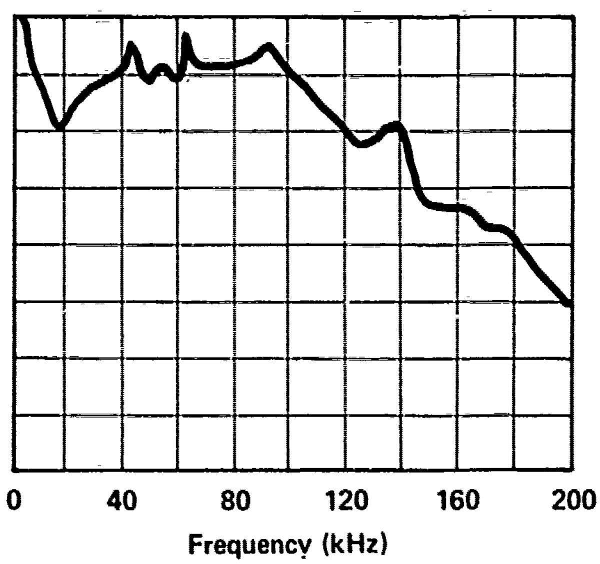
SERVO VALVE – MOOG 35
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 8 GPM
E-203



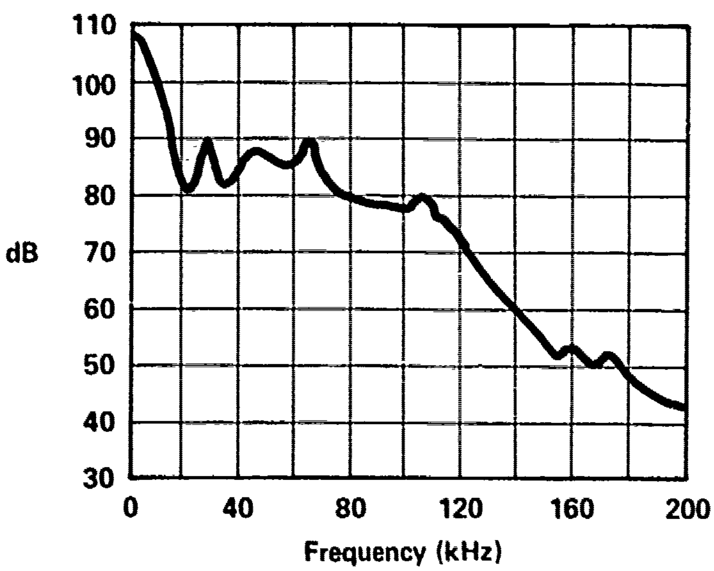
SERVO VALVE – MOOG 35
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 4 GPM
E-204



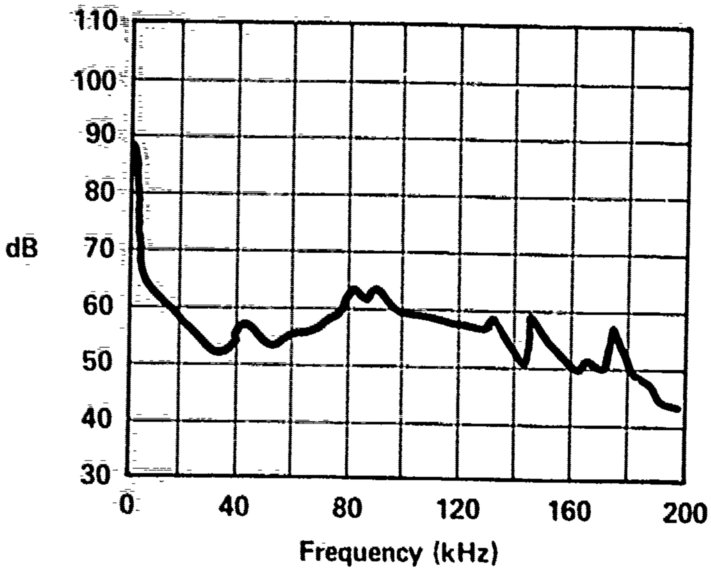
SERVO VALVE – MOOG 35
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 6 GPM
E-205



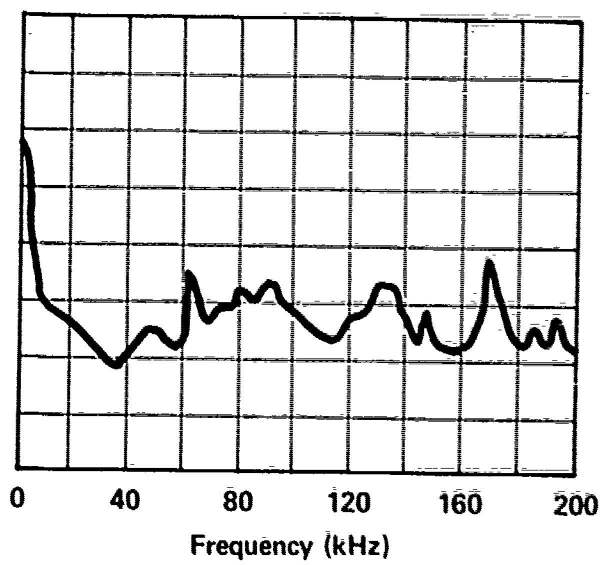
SERVO VALVE – MOOG 35
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 8 GPM
E-206



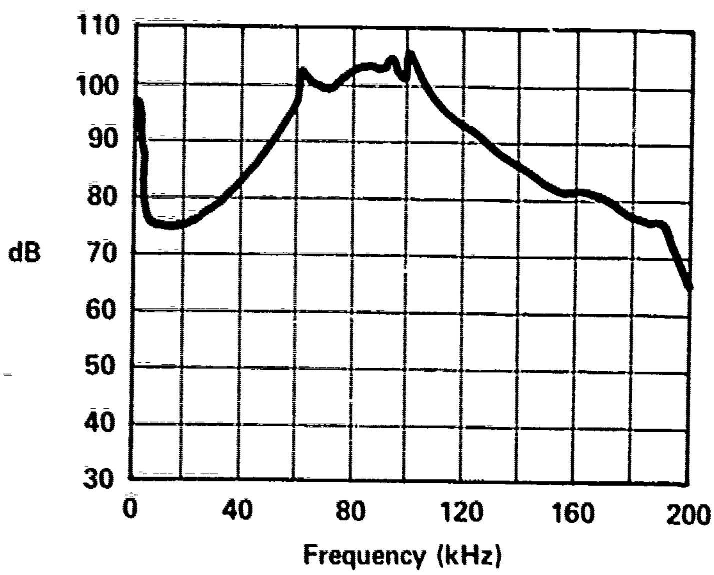
SERVO VALVE – MOOG 35
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 10 GPM
E-207



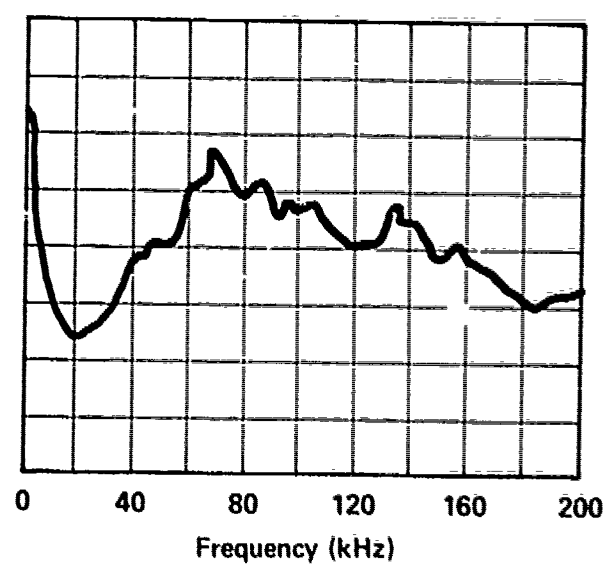
SERVO VALVE – OLSEN
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 0 GPM
E-301



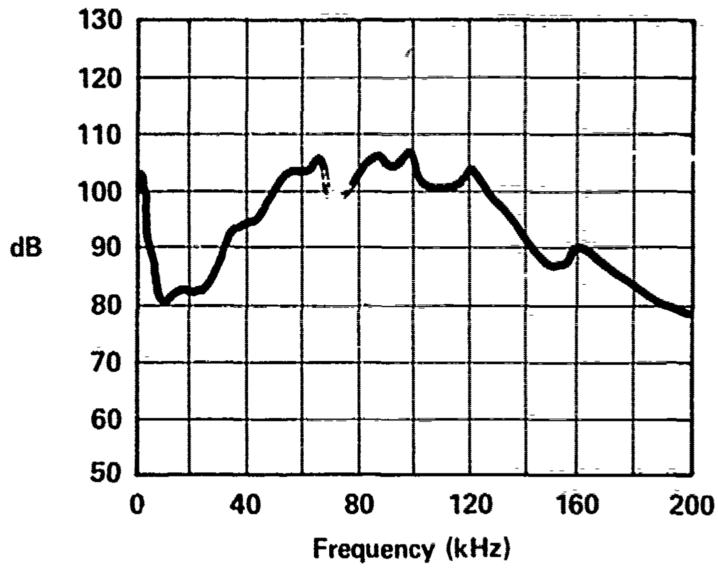
SERVO VALVE – OLSEN
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 0.4 GPM
E-302



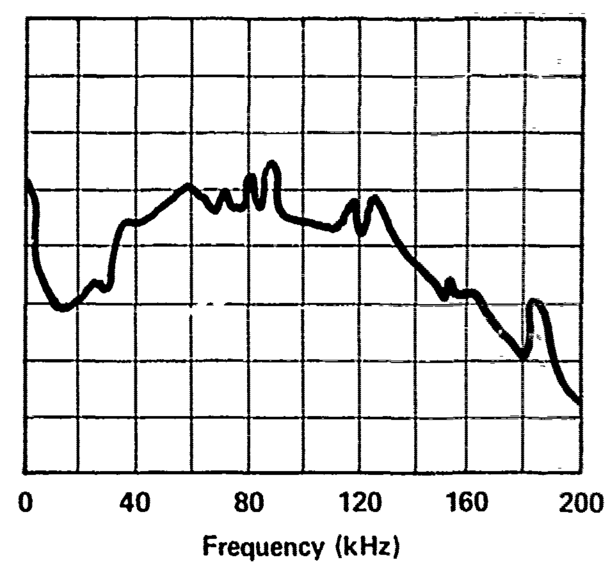
SERVO VALVE – OLSEN
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 1 GPM
E-303



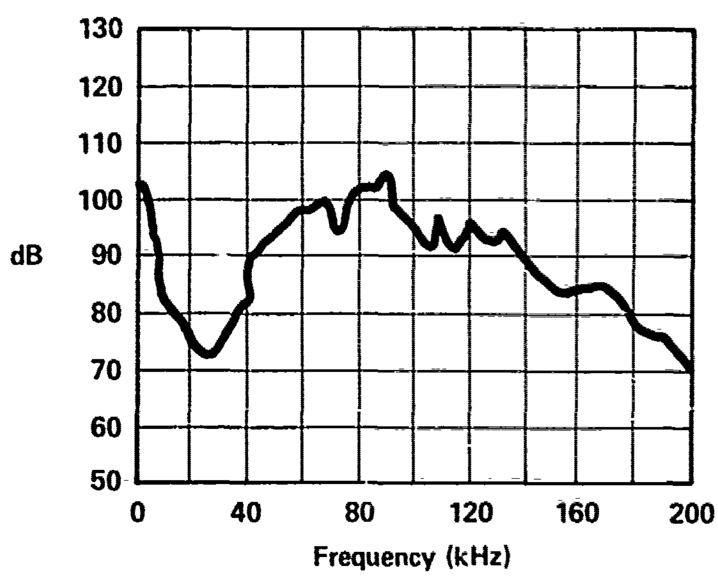
SERVO VALVE – OLSEN
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 4 GPM
E-304



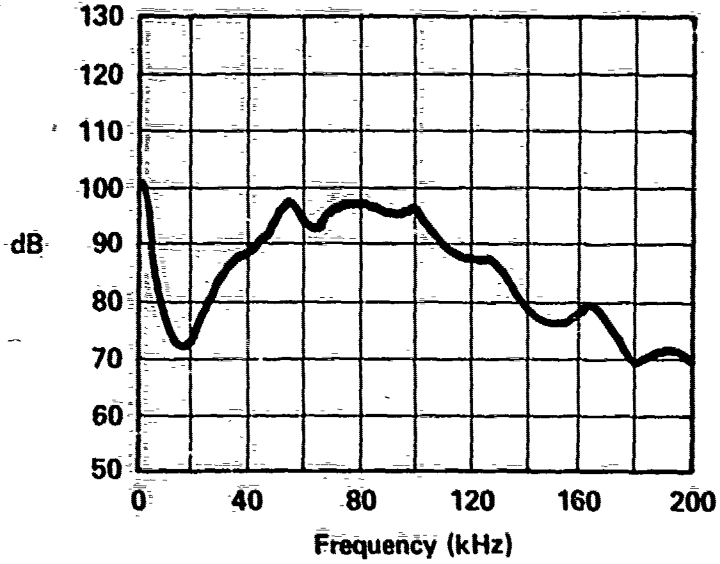
SERVO VALVE – OLSEN
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 6 GPM
E-305



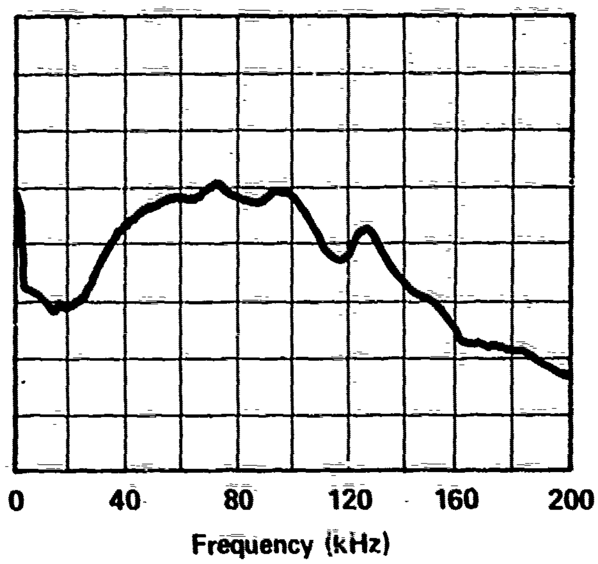
SERVO VALVE – OLSEN
INLET PRESSURE – 1000 PSI
C_1/C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE – 7 GPM
E-306



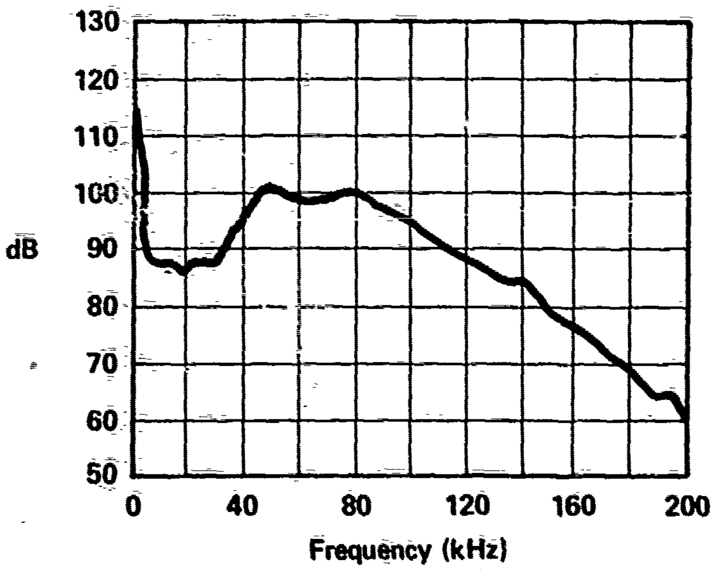
SERVO VALVE – OLSEN
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 1.5 GPM
E-307



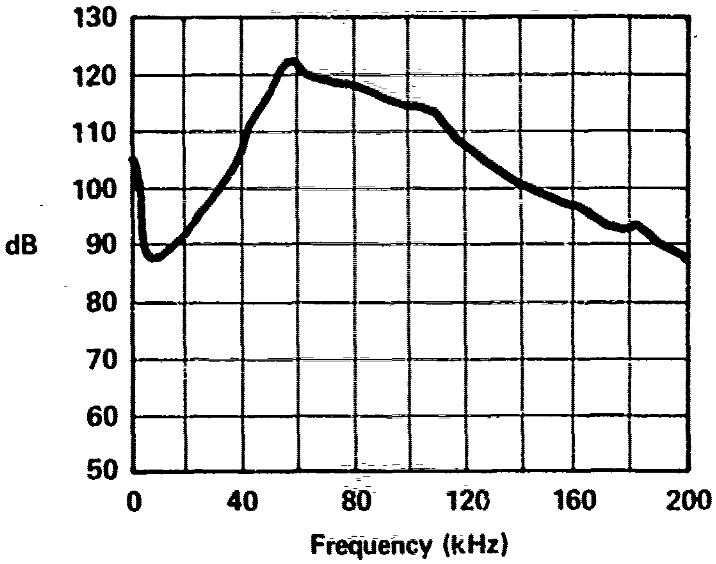
SERVO VALVE – OLSEN
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 4 GPM
E-308



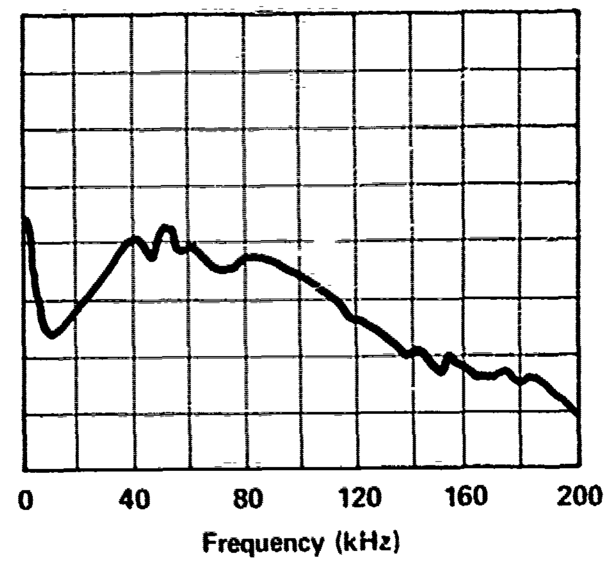
SERVO VALVE – OLSEN
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 6 GPM
E-309



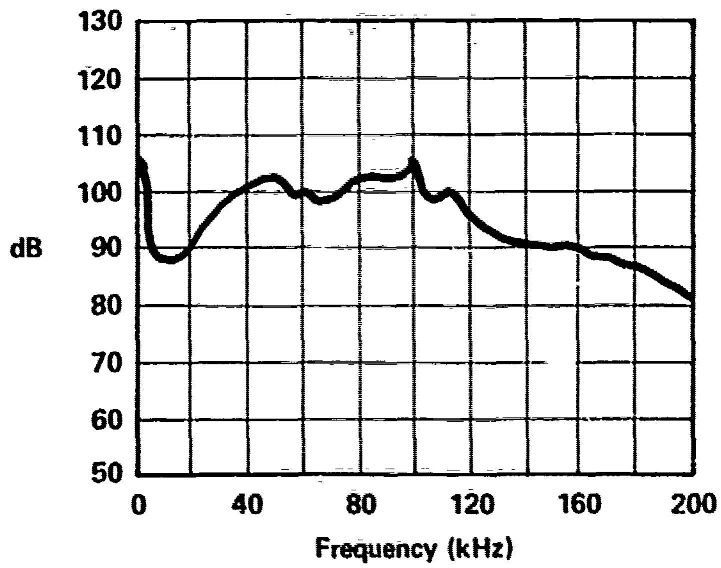
SERVO VALVE – OLSEN
INLET PRESSURE – 1500 PSI
C_1/C_2 PRESSURE – 1000 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE – 9 GPM
E-310



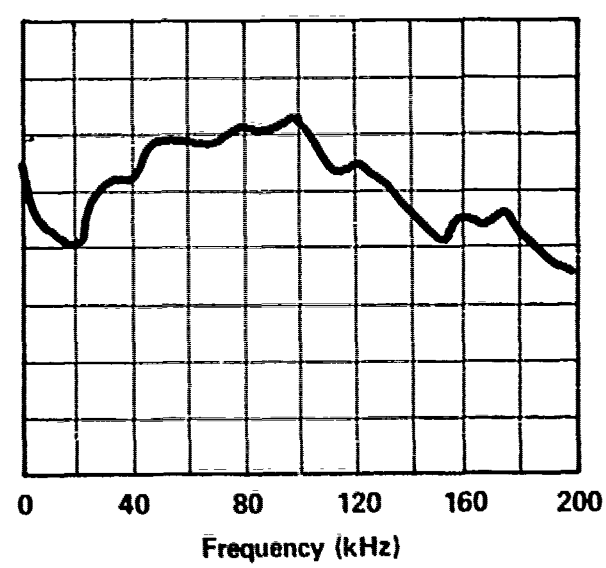
SERVO VALVE & MOTOR – OLSEN & NUTRON
INLET PRESSURE – 1000 PSI
C_1 PRESSURE –
C_2 PRESSURE –
RETURN PRESSURE – 0 PSI
FLOW TO VALVE/MOTOR – 1.8 GPM
MOTOR RPM – 150 RPM
DISK DIAMETER – 24 IN
F-101



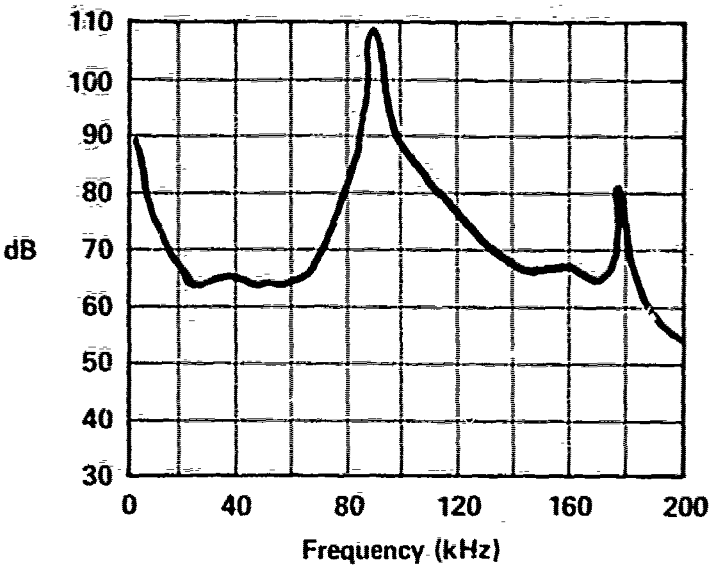
SERVO VALVE & MOTOR – OLSEN & NUTRON
INLET PRESSURE – 1000 PSI
C_1 PRESSURE – 700 PSI
C_2 PRESSURE – 300 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE/MOTOR – 3.8 GPM
MOTOR RPM – 300 RPM
DISK DIAMETER – 24 IN
F-102



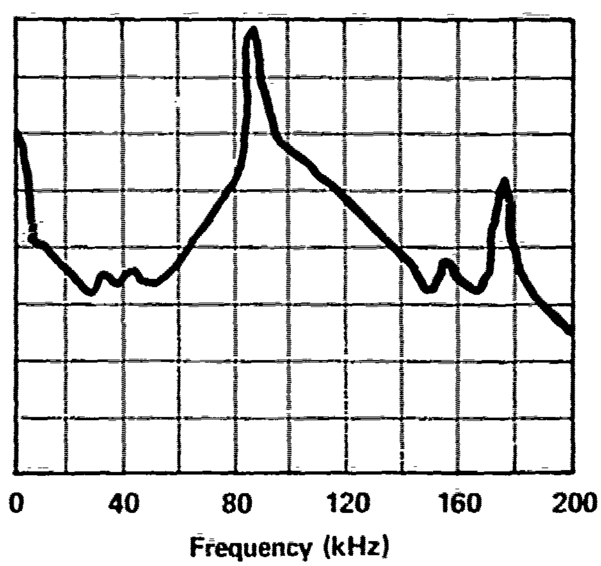
SERVO VALVE & MOTOR – OLSEN & NUTRON
INLET PRESSURE – 1000 PSI
C_1 PRESSURE – 900 PSI
C_2 PRESSURE – 100 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE/MOTOR – 5.2 GPM
MOTOR RPM – 450 RPM
DISK DIAMETER – 24 IN
F-103



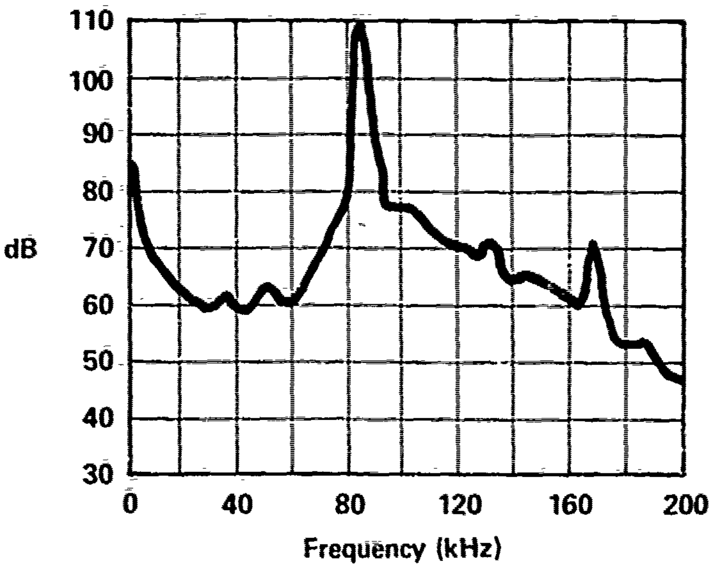
SERVO VALVE & MOTOR – OLSEN & NUTRON
INLET PRESSURE – 1450 PSI
C_1 PRESSURE – 1350 PSI
C_2 PRESSURE – 100 PSI
RETURN PRESSURE – 0 PSI
FLOW TO VALVE/MOTOR – 7.4 GPM
MOTOR RPM – 600 RPM
DISK DIAMETER – 24 IN
F-104



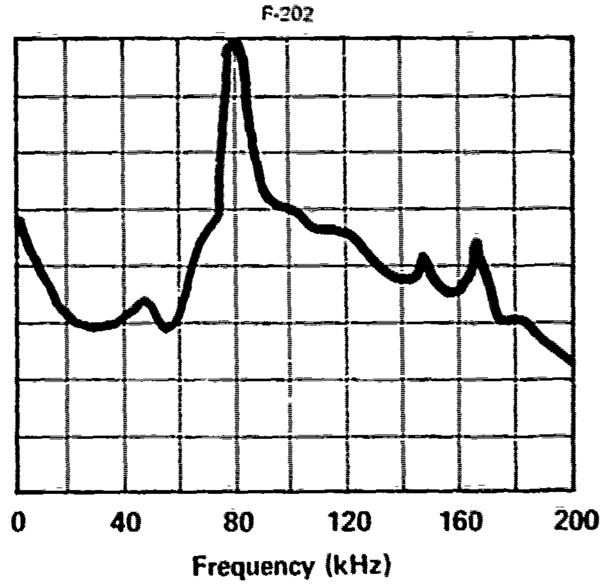
SERVO VALVE & MOTOR – MOOG 74 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 500 PSI
C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 300 PSI
FLOW TO VALVE/MOTOR – 0 GPM
MOTOR RPM – 0 RPM
DISK DIAMETER – 35.75 IN
F-201



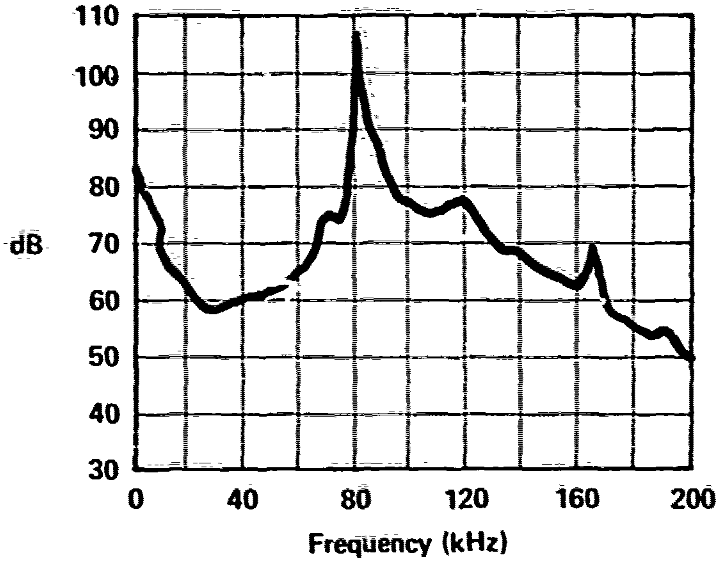
SERVO VALVE & MOTOR – MOOG 74 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1000 PSI
C_2 PRESSURE – 900 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 0.5 GPM
MOTOR RPM – 60 RPM
DISK DIAMETER – 35.75 IN
F-202



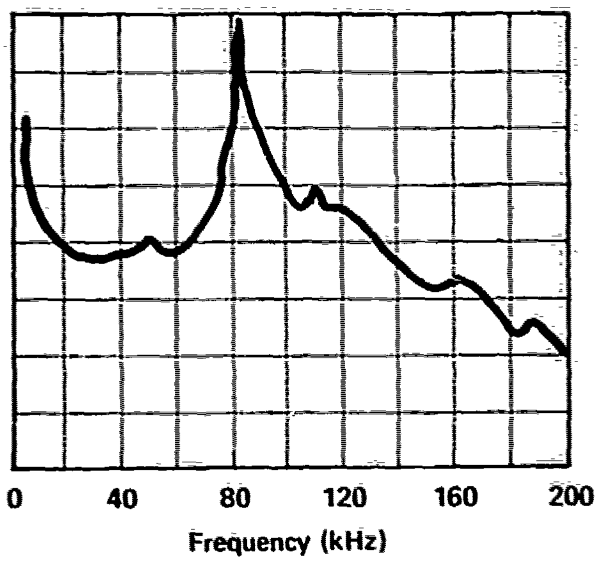
SERVO VALVE & MOTOR – MOOG 74 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1100 PSI
C_2 PRESSURE – 900 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 2 GPM
MOTOR RPM – 120 RPM
DISK DIAMETER – 35.75 IN
F-203



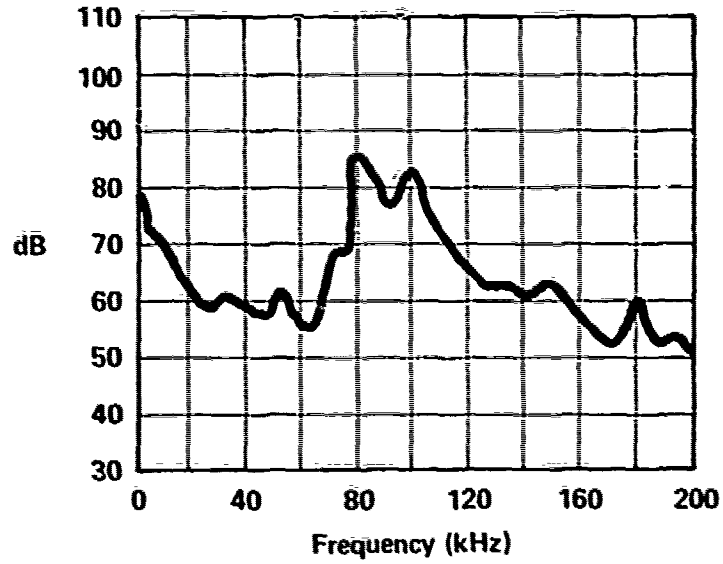
SERVO VALVE & MOTOR – MOOG 74 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1100 PSI
C_2 PRESSURE – 850 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 2.6 GPM
MOTOR RPM – 150 RPM
DISK DIAMETER – 35.75 IN
F-204



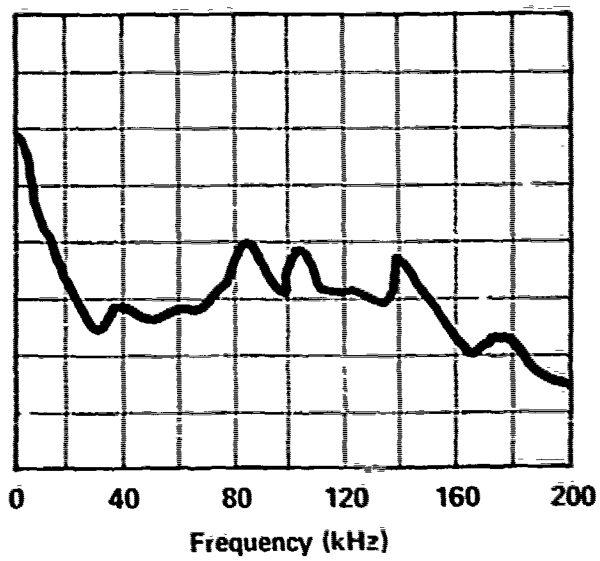
SERVO VALVE & MOTOR – MOOG 74 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1150 PSI
C_2 PRESSURE – 800 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 3.2 GPM
MOTOR RPM – 180 RPM
DISK DIAMETER – 35.75 IN
F-205



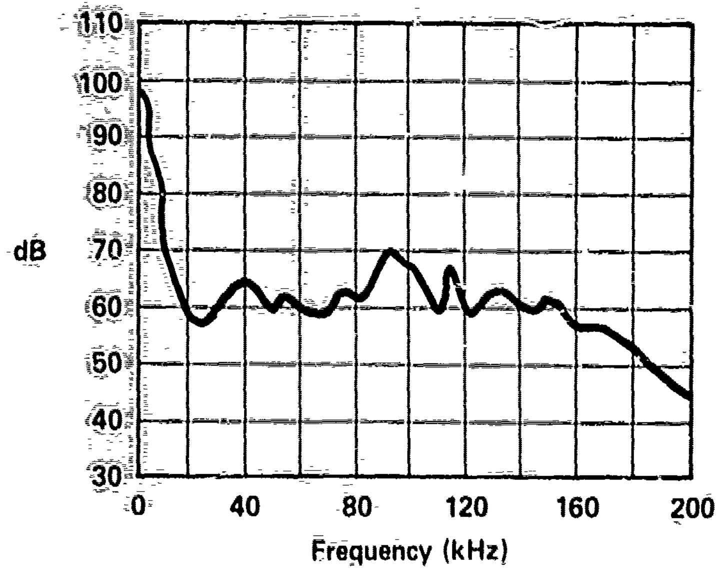
SERVO VALVE & MOTOR – MOOG 74 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1200 PSI
C_2 PRESSURE – 750 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 3.6 GPM
MOTOR RPM – 210 RPM
DISK DIAMETER – 35.75 IN
F-206



SERVO VALVE & MOTOR – MOOG 74 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1350 PSI
C_2 PRESSURE – 700 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 4.6 GPM
MOTOR RPM – 246 RPM
DISK DIAMETER – 35.75 IN
F-207

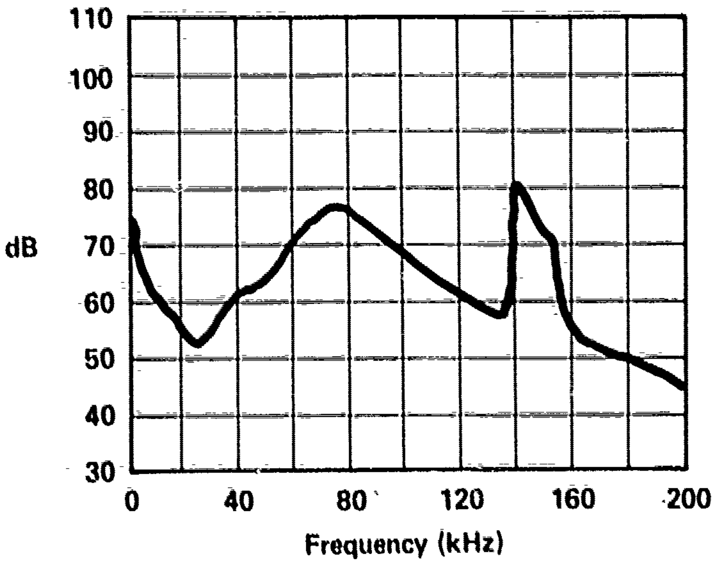


SERVO VALVE & MOTOR – MOOG 74 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1450 PSI
C_2 PRESSURE – 700 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 5.1 GPM
MOTOR RPM – 270 RPM
DISK DIAMETER – 35.75 IN
F-208

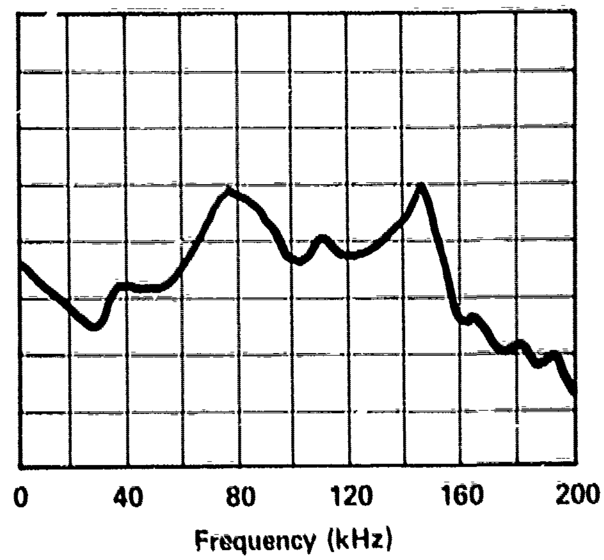


SERVO VALVE & MOTOR – MOOG 74 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1500 PSI
C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 5 GPM
MOTOR RPM – 282 RPM
DISK DIAMETER – 35.75 IN

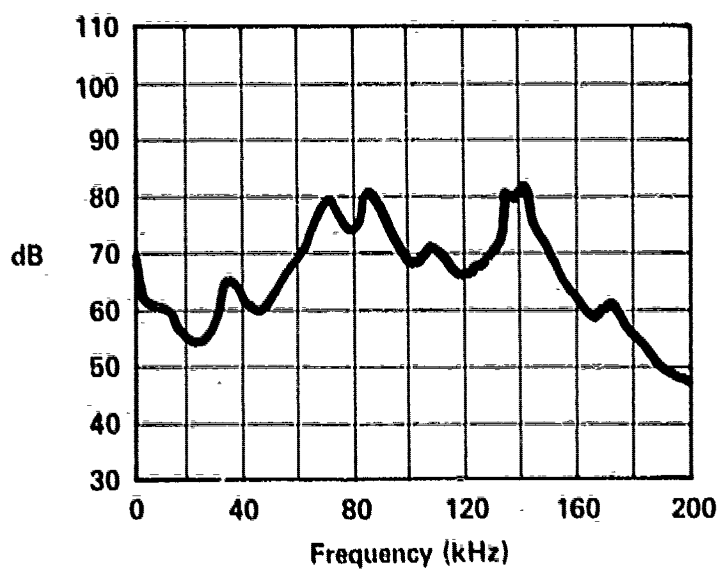
F-209



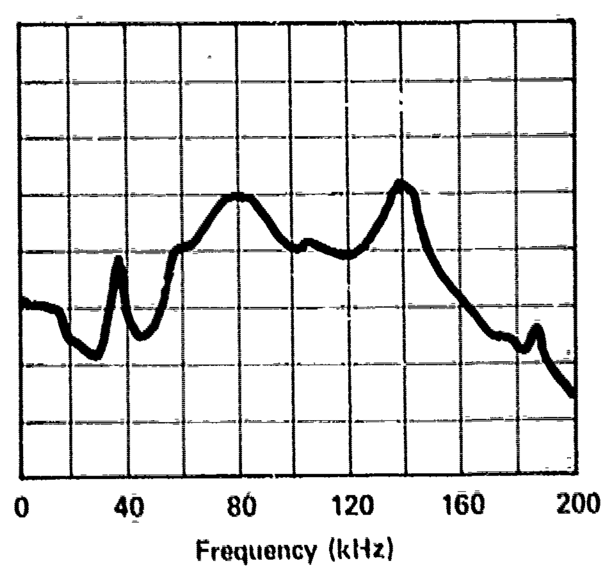
SERVO VALVE & MOTOR – MOOG 35 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1150 PSI
C_2 PRESSURE – 900 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 0.5 GPM
MOTOR RPM – 30 RPM
DISK DIAMETER – 35.75 IN
F-301



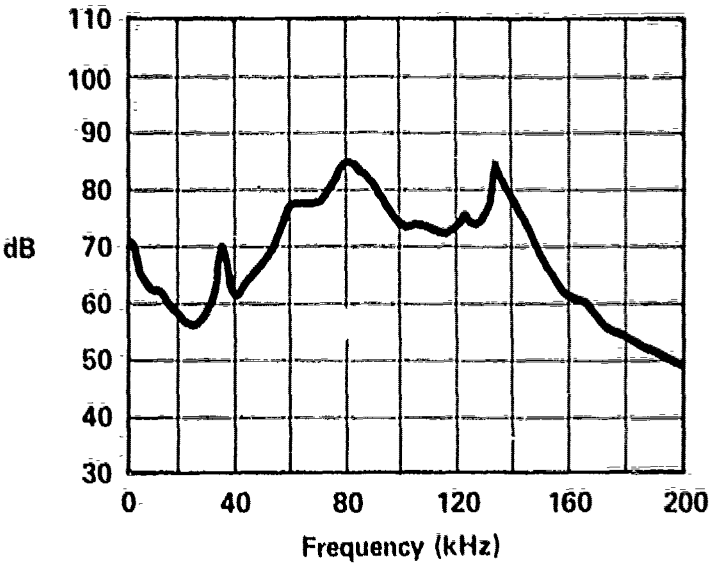
SERVO VALVE & MOTOR – MOOG 35 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1100 PSI
C_2 PRESSURE – 950 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 1 GPM
MOTOR RPM – 60 RPM
DISK DIAMETER – 35.75 IN
F-302



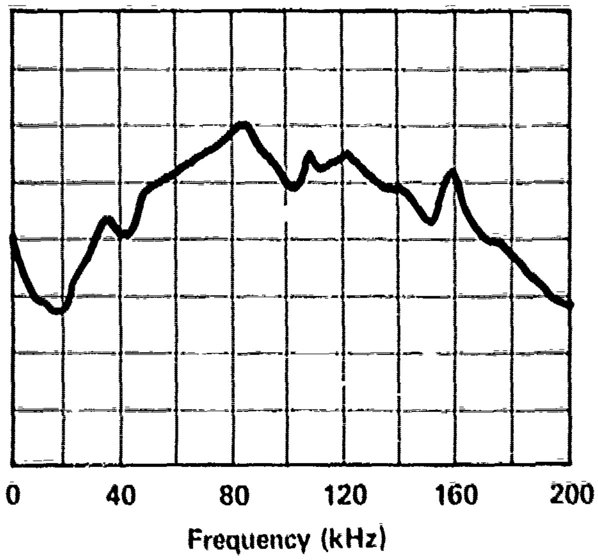
SERVO VALVE & MOTOR – MOOG 35 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1150 PSI
C_2 PRESSURE – 800 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 1.5 GPM
MOTOR RPM – 90 RPM
DISK DIAMETER – 35.75 IN
F-303



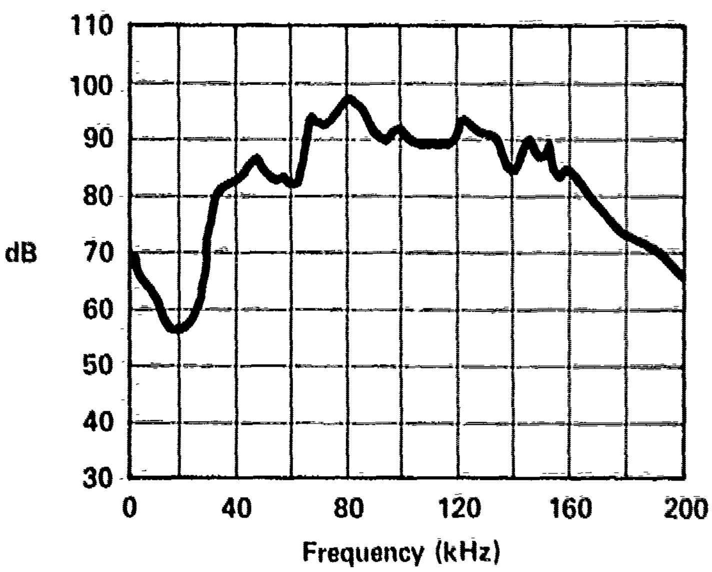
SERVO VALVE & MOTOR – MOOG 35 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1200 PSI
C_2 PRESSURE – 800 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 1.8 GPM
MOTOR RPM – 120 RPM
DISK DIAMETER – 35.75 IN
F-304



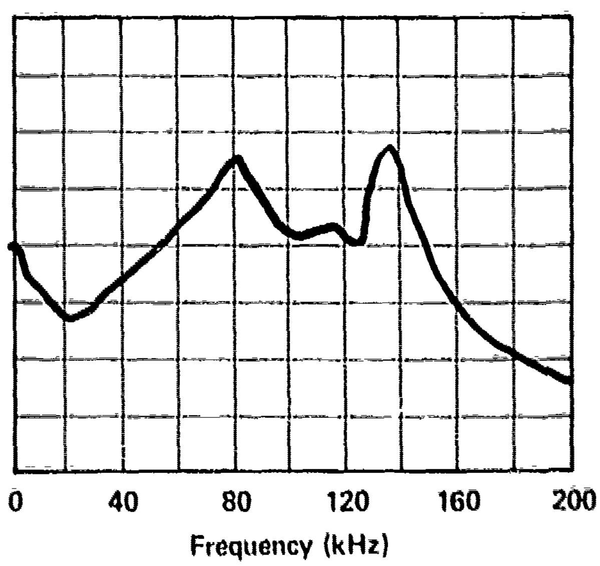
SERVO VALVE & MOTOR – MOOG 35 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1225 PSI
C_2 PRESSURE – 775 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 2.0 GPM
MOTOR RPM – 150 RPM
DISK DIAMETER – 35.75 IN
F-305



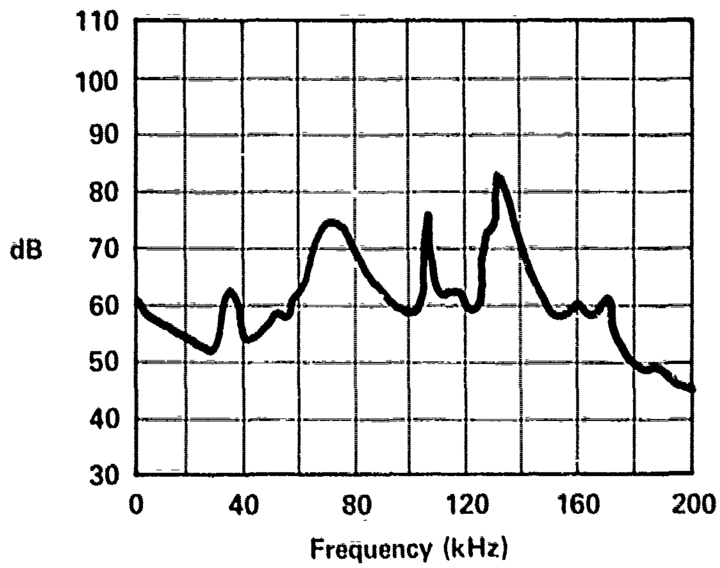
SERVO VALVE & MOTOR – MOOG 35 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1250 PSI
C_2 PRESSURE – 700 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 3.2 GPM
MOTOR RPM – 180 RPM
DISK DIAMETER – 35.75 IN
F-306



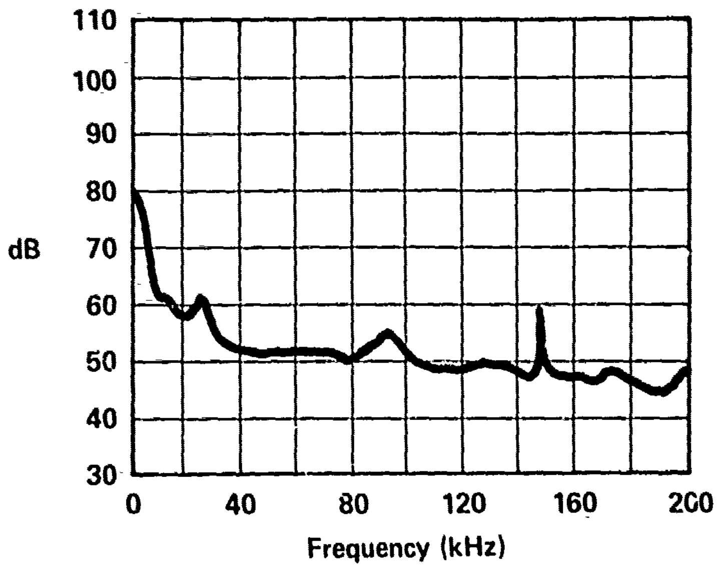
SERVO VALVE & MOTOR – MOOG 35 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1200 PSI
C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 3.8 GPM
MOTOR RPM – 210 RPM
DISK DIAMETER – 35.75 IN
F-307



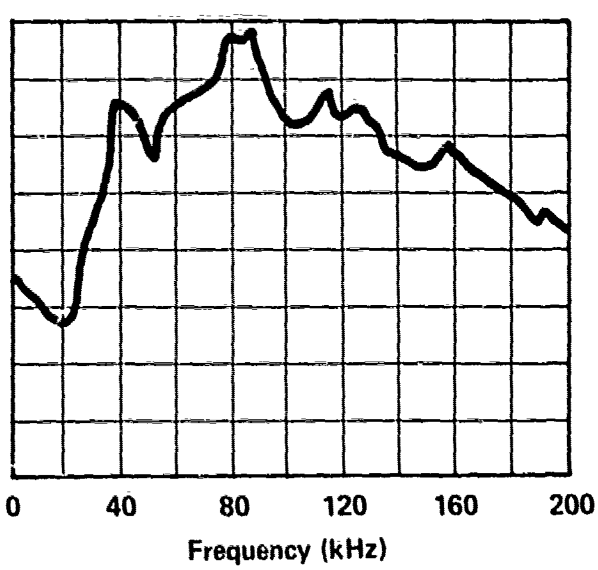
SERVO VALVE & MOTOR – MOOG 35 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1350 PSI
C_2 PRESSURE – 600 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 4.1 GPM
MOTOR RPM – 240 RPM
DISK DIAMETER – 35.75 IN
F-308



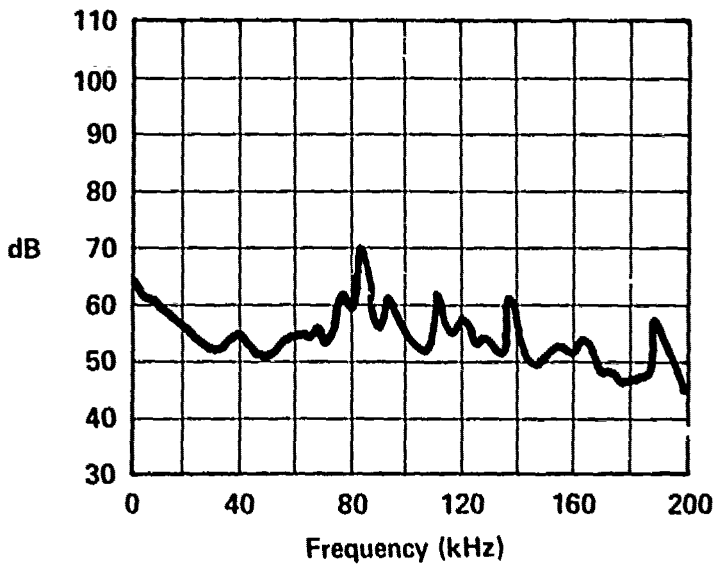
SERVO VALVE & MOTOR – MOOG 35 & WSI
INLET PRESSURE – 1500 PSI
C_1 PRESSURE – 1450 PSI
C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 500 PSI
FLOW TO VALVE/MOTOR – 5 GPM
MOTOR RPM – 270 RPM
DISK DIAMETER – 35.75 IN
F-309



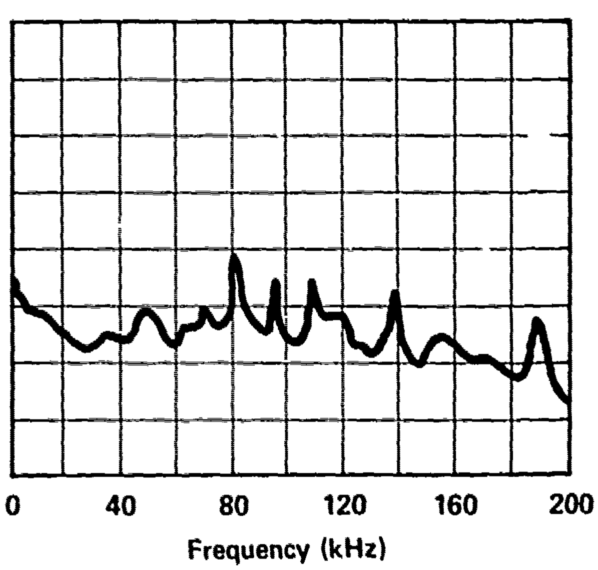
SERVO VALVE & MOTOR – OLSEN & WSI
INLET PRESSURE – 1000 PSI
C_1 PRESSURE – 580 PSI
C_2 PRESSURE – 450 PSI
RETURN PRESSURE – 100 PSI
FLOW TO VALVE/MOTOR – 0 GPM
MOTOR RPM – 0 RPM
DISK DIAMETER – 35.75 IN
F-401



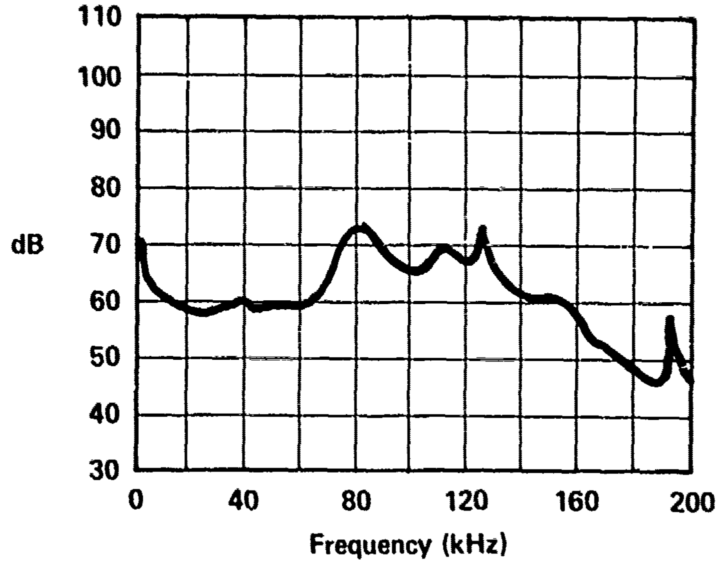
SERVO VALVE & MOTOR – OLSEN & WSI
INLET PRESSURE – 1000 PSI
C_1 PRESSURE – 700 PSI
C_2 PRESSURE – 500 PSI
RETURN PRESSURE – 125 PSI
FLOW TO VALVE/MOTOR – 2 GPM
MOTOR RPM – 144 RPM
DISK DIAMETER – 35.75 IN
F-402



SERVO VALVE & MOTOR – OLSEN & WSI
INLET PRESSURE – 1000 PSI
C_1 PRESSURE – 950 PSI
C_2 PRESSURE – 150 PSI
RETURN PRESSURE – 125 PSI
FLOW TO VALVE/MOTOR – 4.8 GPM
MOTOR RPM – 252 RPM
DISK DIAMETER – 35.75 IN
F-403



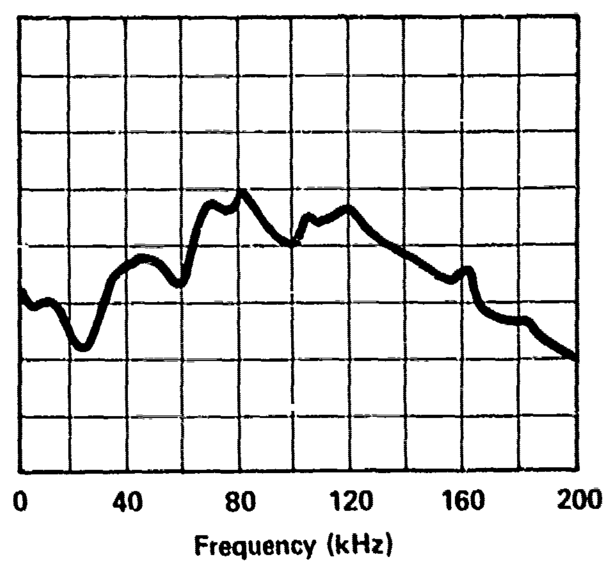
SERVO VALVE & MOTOR – OLSEN & WSI
INLET PRESSURE – 1125 PSI
C_1 PRESSURE – 1000 PSI
C_2 PRESSURE – 125 PSI
RETURN PRESSURE – 125 PSI
FLOW TO VALVE/MOTOR – 4.9 GPM
MOTOR RPM – 276 RPM
DISK DIAMETER – 35.75 IN
F-404



SERVO VALVE & MOTOR – OLSEN & WSI

INLET PRESSURE –	1250 PSI
C_1 PRESSURE –	1150 PSI
C_2 PRESSURE –	150 PSI
RETURN PRESSURE –	100 PSI
FLOW TO VALVE/MOTOR –	5 GPM
MOTOR RPM –	300 RPM
DISK DIAMETER –	35.75 IN

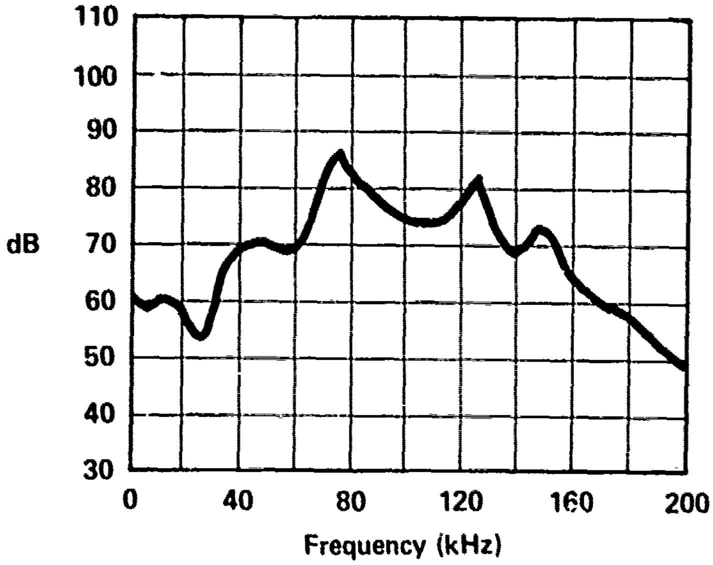
F-405



SERVO VALVE & MOTOR – OLSEN & WSI

INLET PRESSURE –	1500 PSI
C_1 PRESSURE –	1200 PSI
C_2 PRESSURE –	850 PSI
RETURN PRESSURE –	500 PSI
FLOW TO VALVE/MOTOR –	2 GPM
MOTOR RPM –	108 RPM
DISK DIAMETER –	35.75 IN

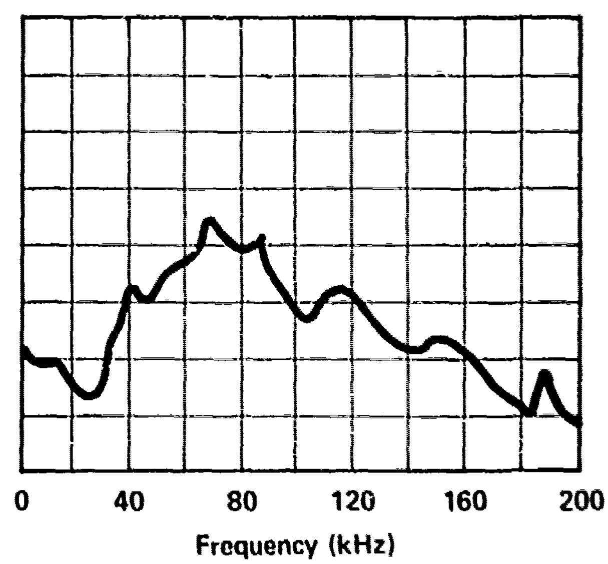
F-406



SERVO VALVE & MOTOR – OLSEN & WSI

INLET PRESSURE –	1500 PSI
C_1 PRESSURE –	1200 PSI
C_2 PRESSURE –	800 PSI
RETURN PRESSURE –	500 PSI
FLOW TO VALVE/MOTOR –	2.5 GPM
MOTOR RPM –	150 RPM
DISK DIAMETER –	35.75 IN

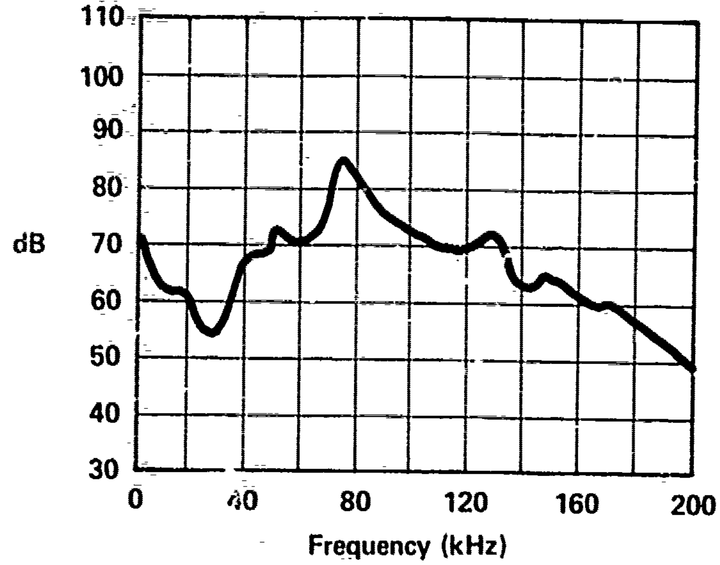
F-407



SERVO VALVE & MOTOR – OLSEN & WSI

INLET PRESSURE –	1500 PSI
C_1 PRESSURE –	1100 PSI
C_2 PRESSURE –	900 PSI
RETURN PRESSURE –	500 PSI
FLOW TO VALVE/MOTOR –	2.6 GPM
MOTOR RPM –	156 RPM
DISK DIAMETER –	35.75 IN

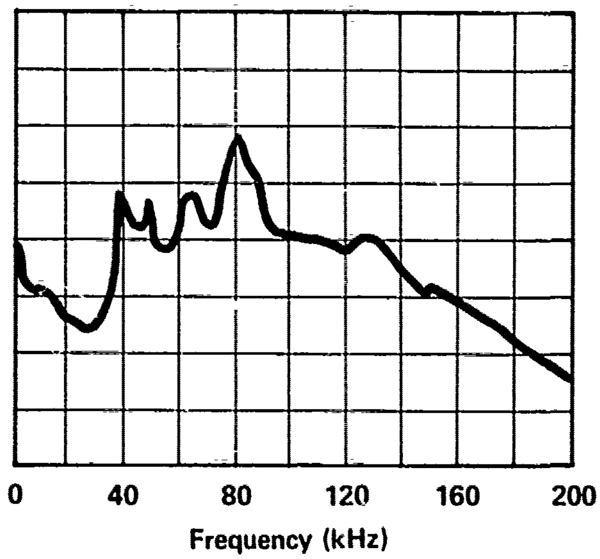
F-408



SERVO VALVE & MOTOR – OLSEN & WSI

INLET PRESSURE –	1500 PSI
C_1 PRESSURE –	1150 PSI
C_2 PRESSURE –	800 PSI
RETURN PRESSURE –	500 PSI
FLOW TO VALVE/MOTOR –	3 GPM
MOTOR RPM –	180 RPM
DISK DIAMETER –	35.75 IN

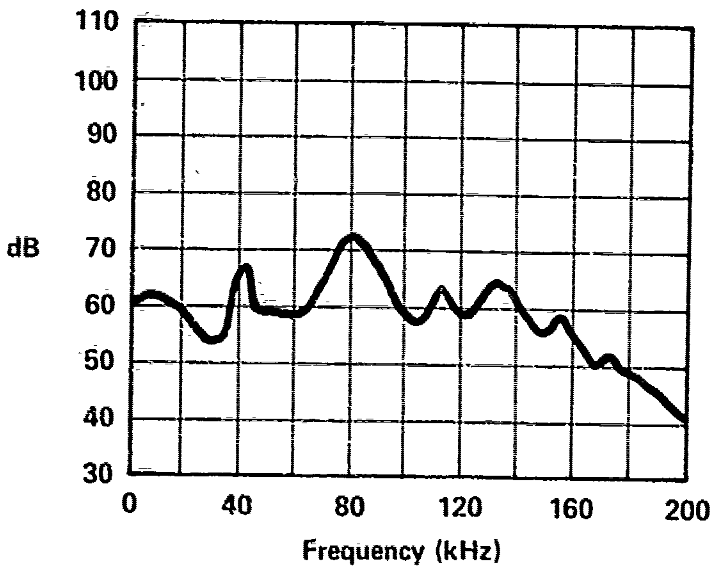
F-409



SERVO VALVE & MOTOR – OLSEN & WSI

INLET PRESSURE –	1500 PSI
C_1 PRESSURE –	1200 PSI
C_2 PRESSURE –	800 PSI
RETURN PRESSURE –	500 PSI
FLOW TO VALVE/MOTOR –	4 GPM
MOTOR RPM –	216 RPM
DISK DIAMETER –	35.75 IN

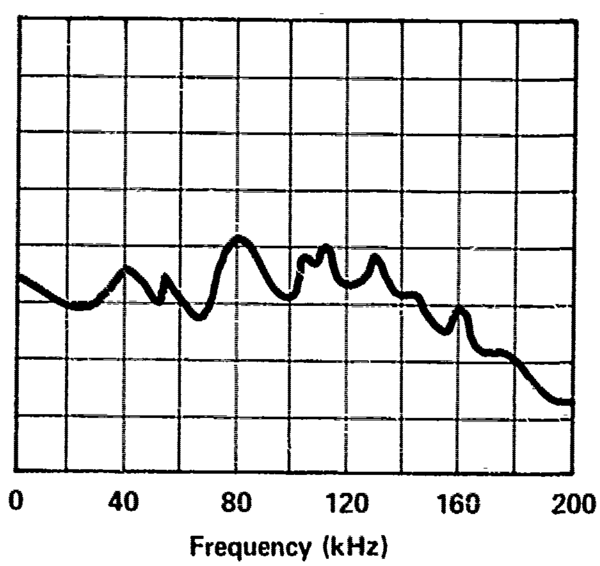
F-410



SERVO VALVE & MOTOR – OLSEN & WSI

INLET PRESSURE –	1500 PSI
C_1 PRESSURE –	1250 PSI
C_2 PRESSURE –	750 PSI
RETURN PRESSURE –	500 PSI
FLOW TO VALVE/MOTOR –	4.5 GPM
MOTOR RPM –	252 RPM
DISK DIAMETER –	35.75 IN

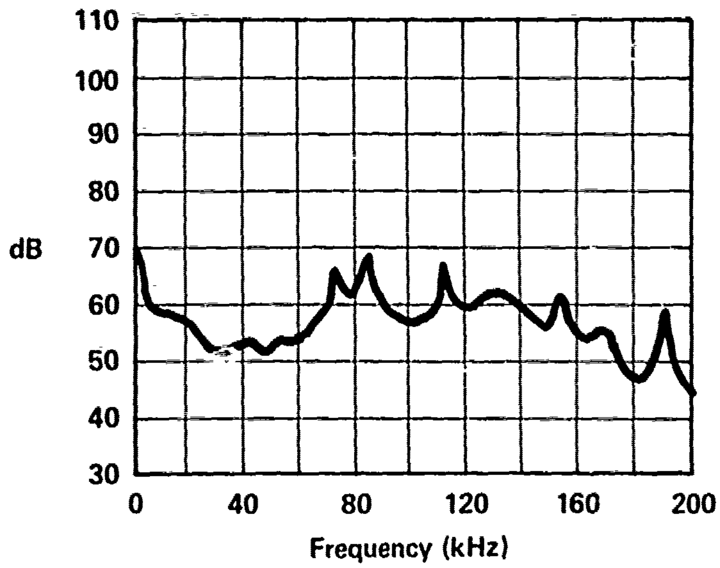
F-411



SERVO VALVE & MOTOR – OLSEN & WSI

INLET PRESSURE –	1500 PSI
C_1 PRESSURE –	1350 PSI
C_2 PRESSURE –	550 PSI
RETURN PRESSURE –	500 PSI
FLOW TO VALVE/MOTOR –	5 GPM
MOTOR RPM –	264 RPM
DISK DIAMETER –	35.75 IN

F-412



SERVO VALVE & MOTOR – OLSEN & WSI

INLET PRESSURE –	1500 PSI
C_1 PRESSURE –	1400 PSI
C_2 PRESSURE –	750 PSI
RETURN PRESSURE –	500 PSI
FLOW TO VALVE/MOTOR –	5 GPM
MOTOR RPM –	276 RPM
DISK DIAMETER –	35.75 IN

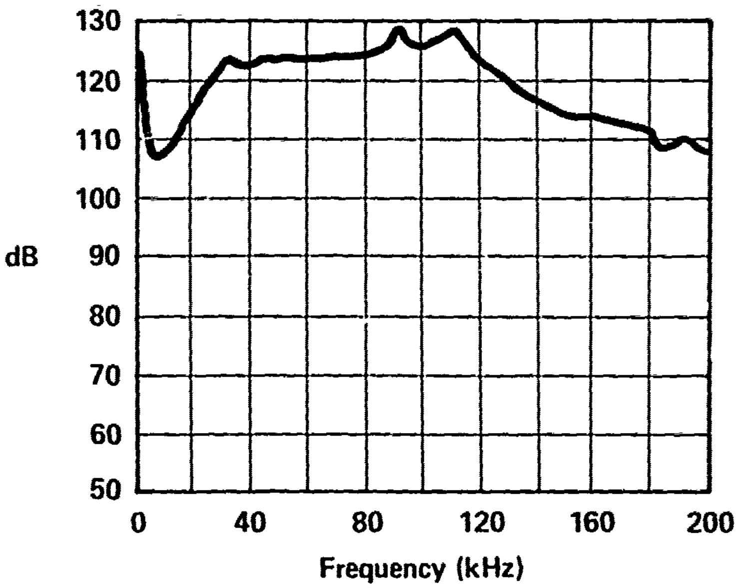
F-413

APPENDIX B

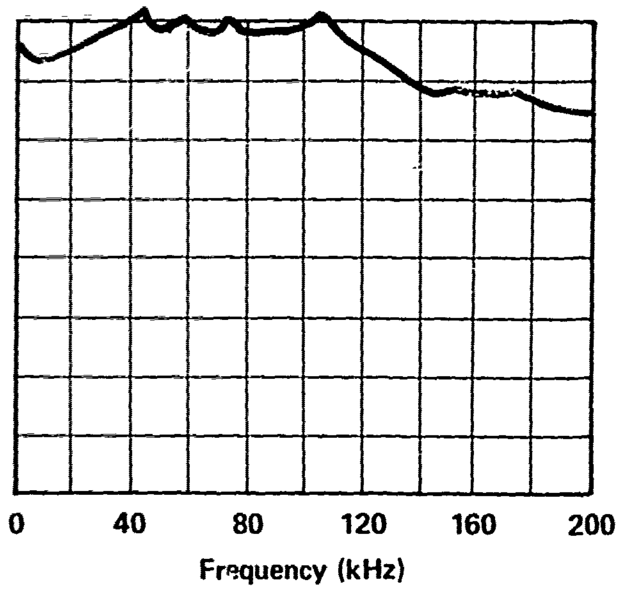
TEST DATA OF SECOND TEST SERIES

GRAPHS

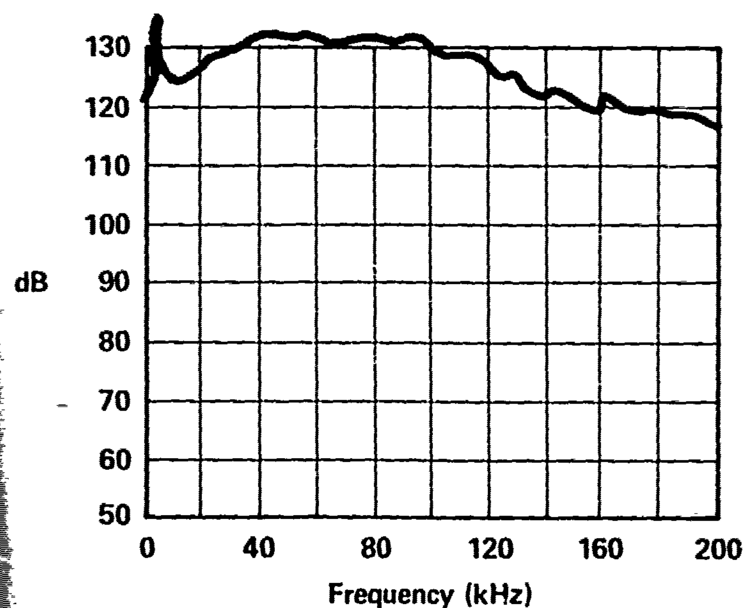
This appendix presents the results of the second series of acoustic tests, depicted by noise profile graphs for each of the components and specified test conditions. The decibel scales for all graphs have a reference of 1 microPascal per hertz per yard (dB//μPa/Hz/yd).



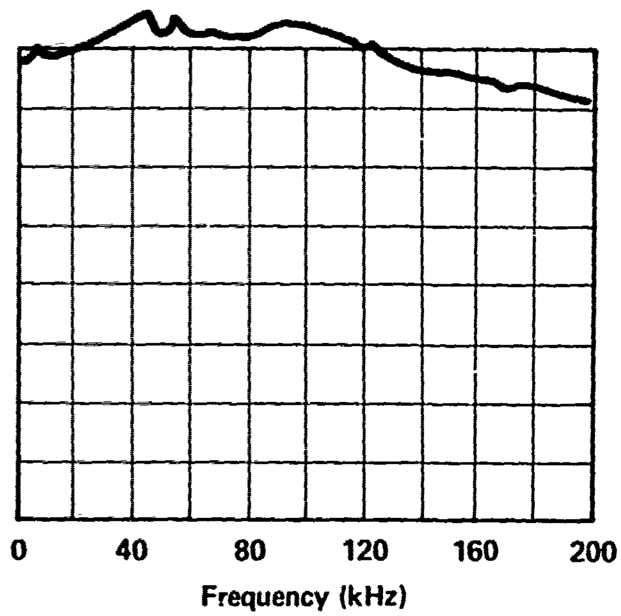
FLOW – 5 GPM
B-316



FLOW – 10 GPM
B-317

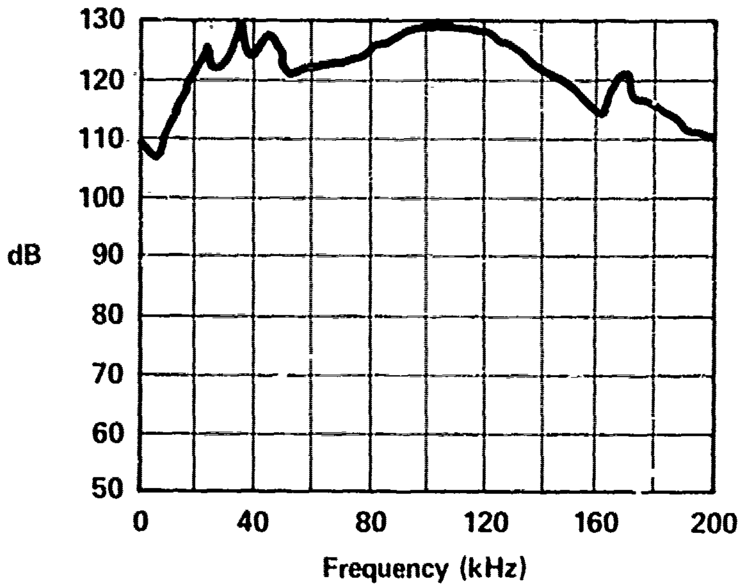


FLOW – 15 GPM
B-318

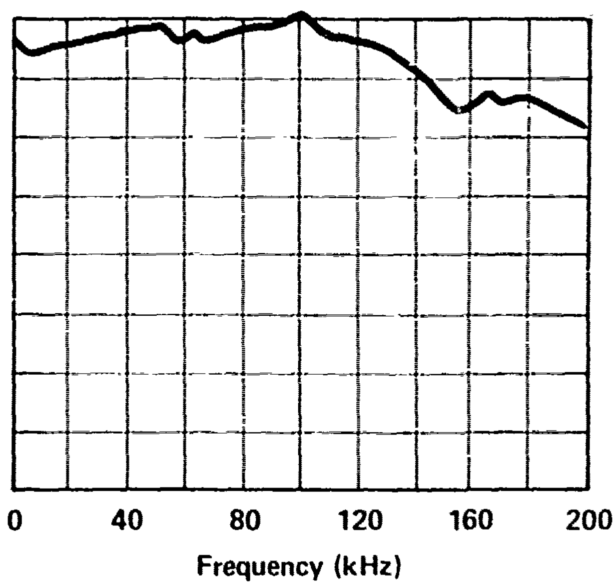


FLOW – 20 GPM
B-319

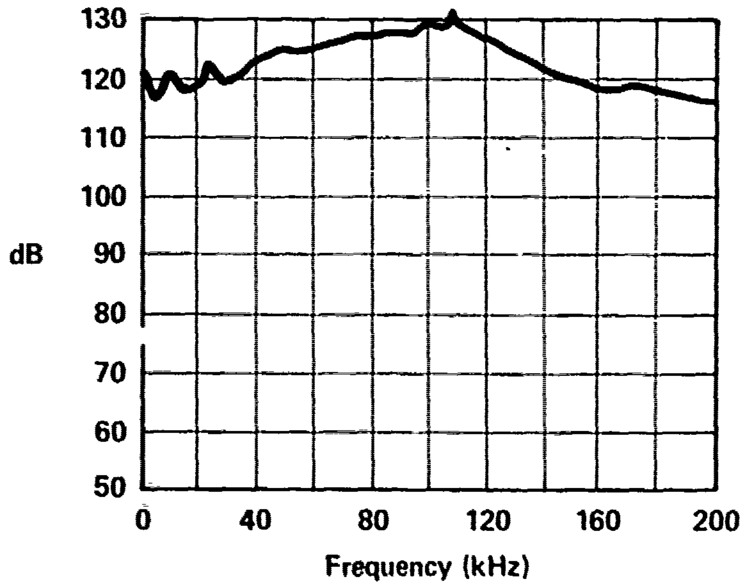
VICKERS RELIEF VALVE =CT-10-C-20
INLET – 1000 PSI
RETURN – 0 PSI
LOCATION – [illegible]C SALTWATER TEST POOL



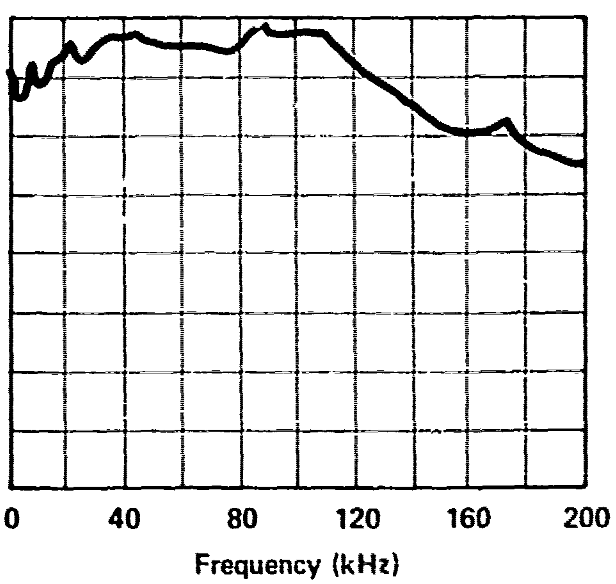
FLOW – 5 GPM
B-320



FLOW – 10 GPM
B-321

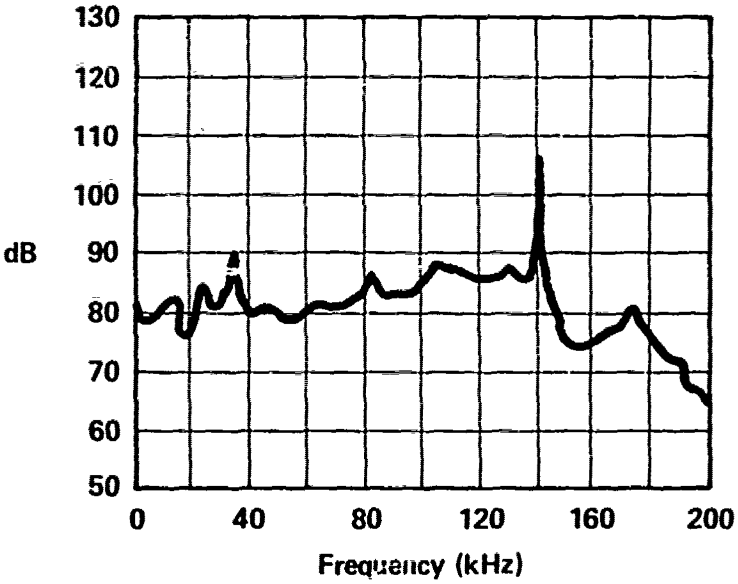


FLOW – 15 GPM
B-322

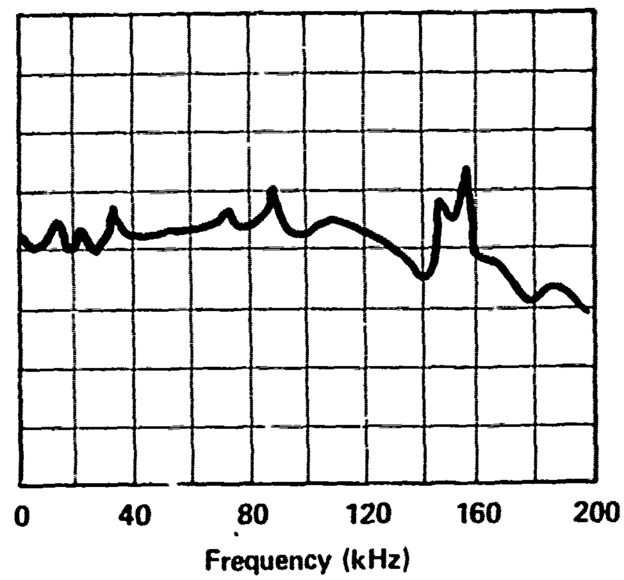


FLOW – 20 GPM
B-323

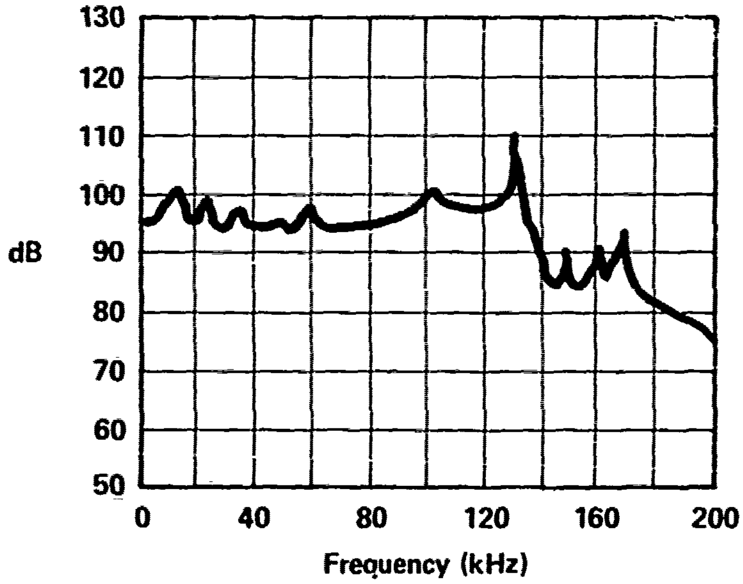
VICKERS RELIEF VALVE =CT-10 C 20
DEGASSED OIL
INLET – 1000 PSI
RETURN – 0 PSI
LOCATION – NUC SALTWATER TEST POOL



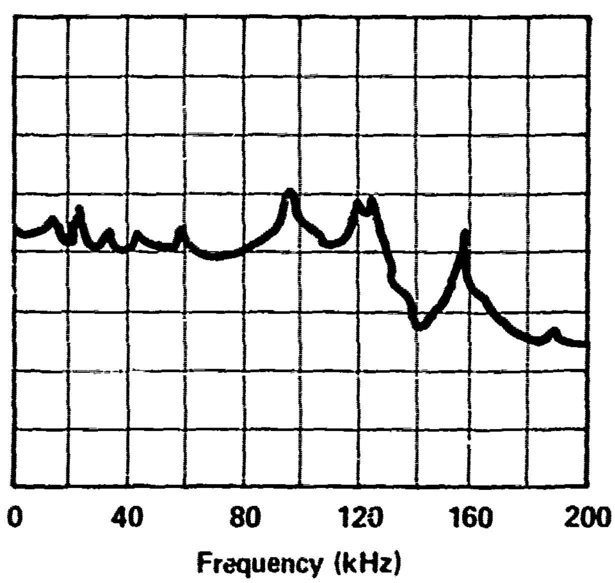
FLOW – 5 GPM
B-324



FLOW – 10 GPM
B-325

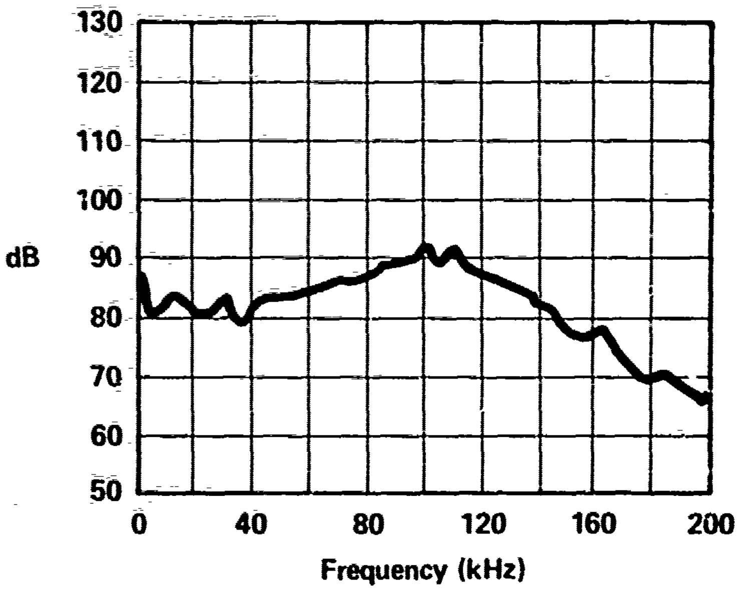


FLOW – 15 GPM
B-326

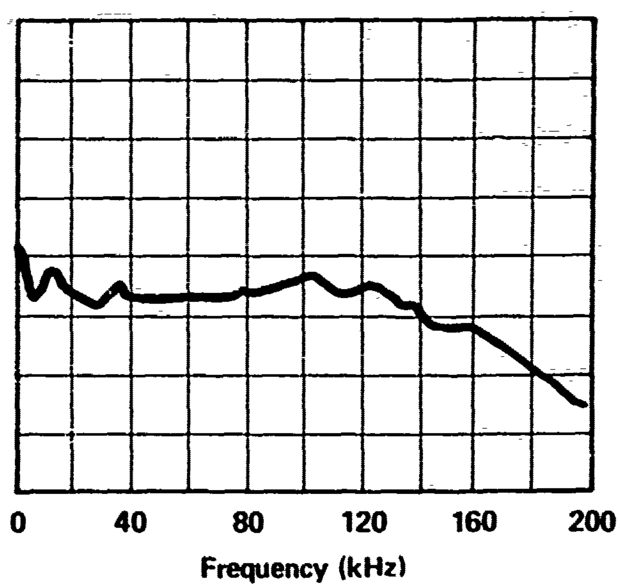


FLOW – 20 GPM
B 327

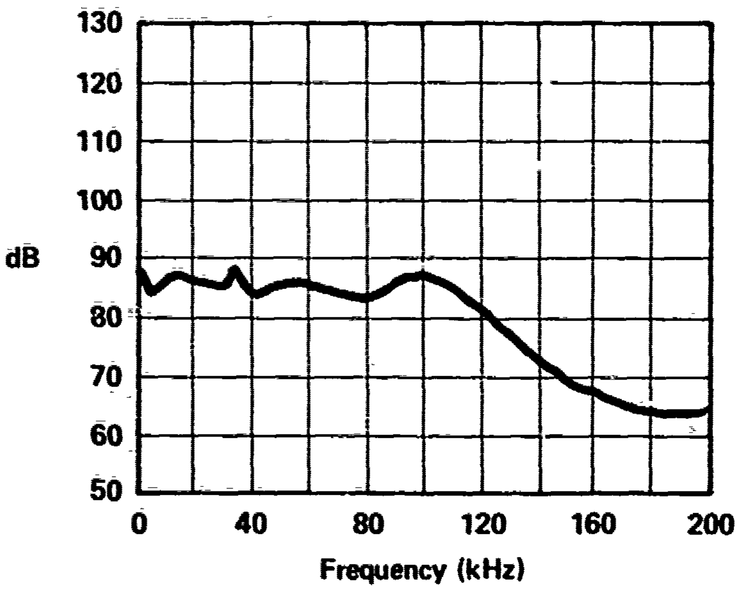
VICKERS RELIEF VALVE NO. CT-10-C-20
INLET – 1500 PSI
RETURN – 500 PSI
LOCATION – NUC SALTWATER TEST POOL



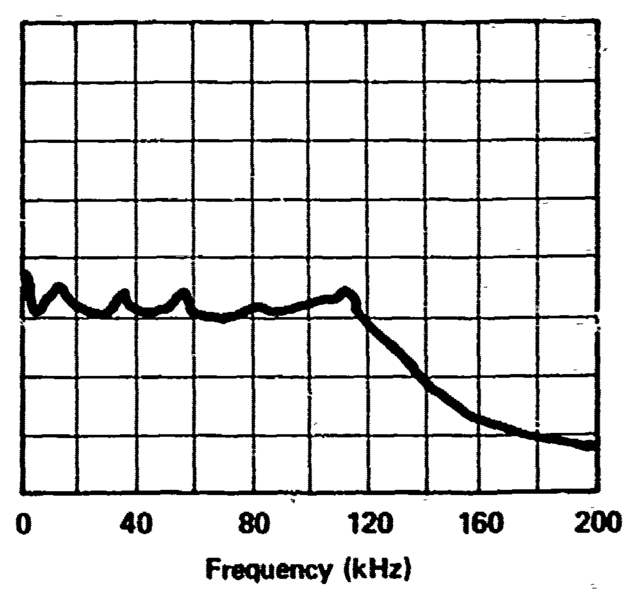
FLOW – 5 GPM
E-401



FLOW – 10 GPM
E-402

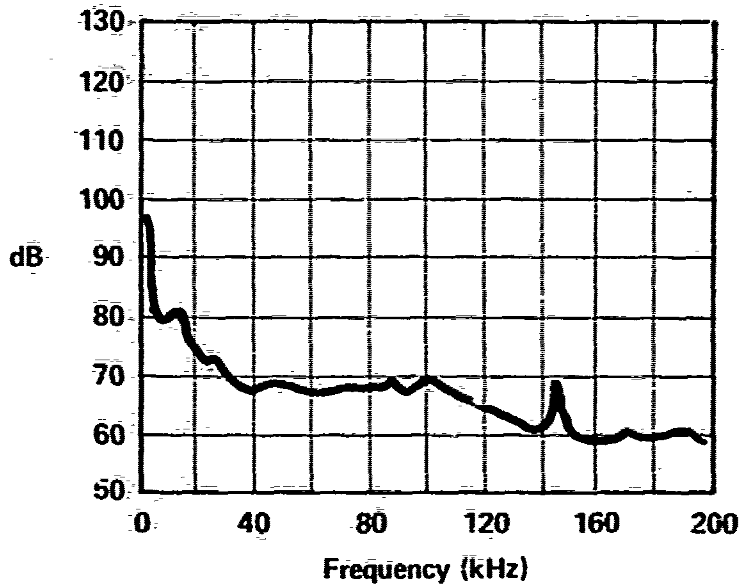


FLOW – 15 GPM
E-403



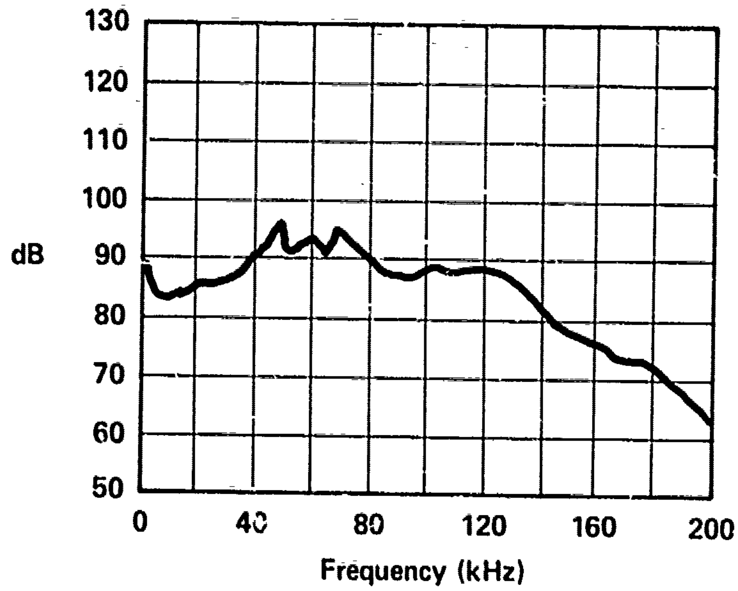
FLOW – 20 GPM
E-404

SANDERS SERVO VALVE NO. SV-438-10P
INLET – 1000 PSI
RETURN – 0 PSI
LOCATION – NUC SALTWATER TEST POOL

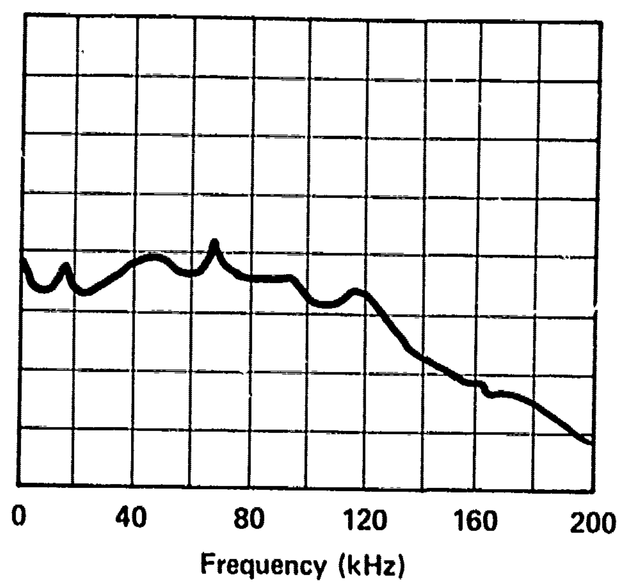


FLOW – 22 GPM
E-405

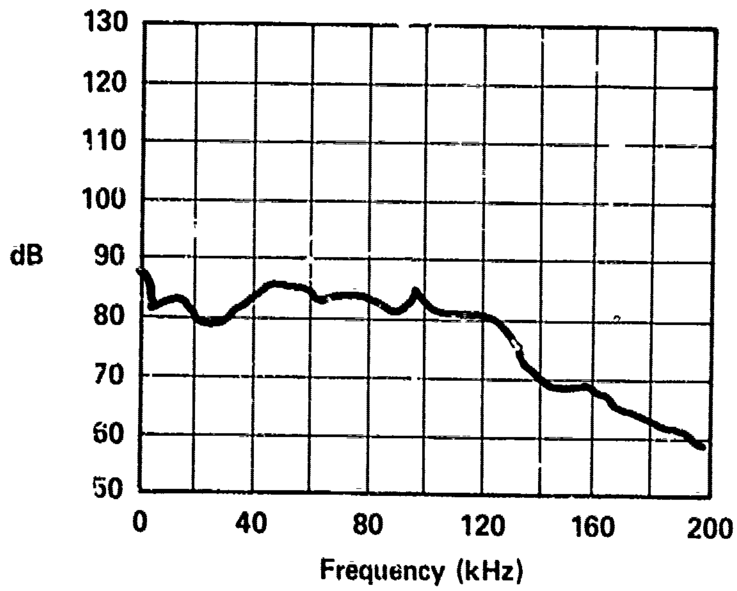
SANDERS SERVO VALVE NO. SV-438-10P
INLET – 500 PSI
RETURN – 0 PSI
LOCATION – NUC SALTWATER TEST POOL



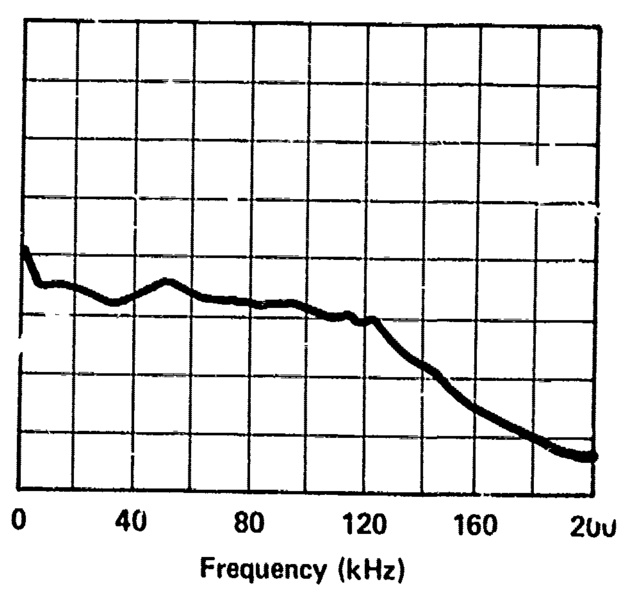
FLOW – 5 GPM
E-406



FLOW – 10 GPM
E-407

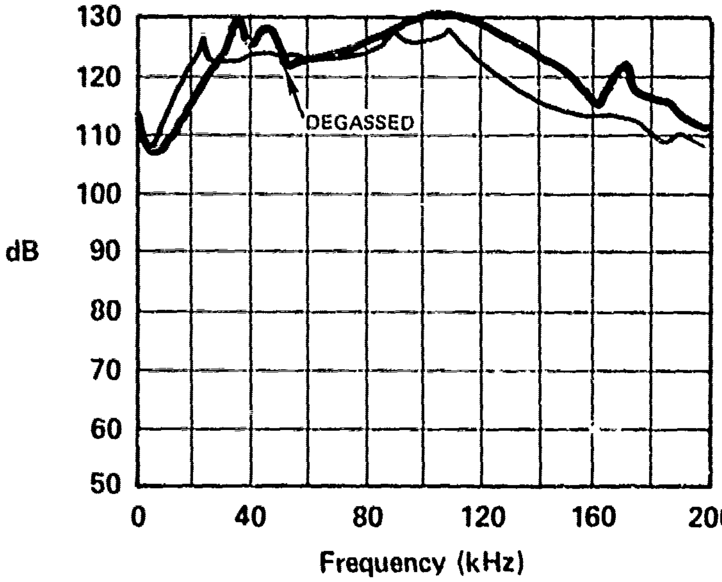


FLOW – 15 GPM
E-408

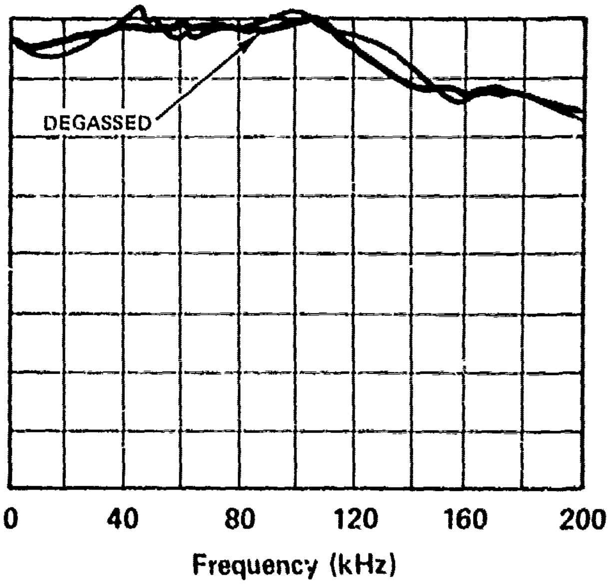


FLOW – 20 GPM
E-409

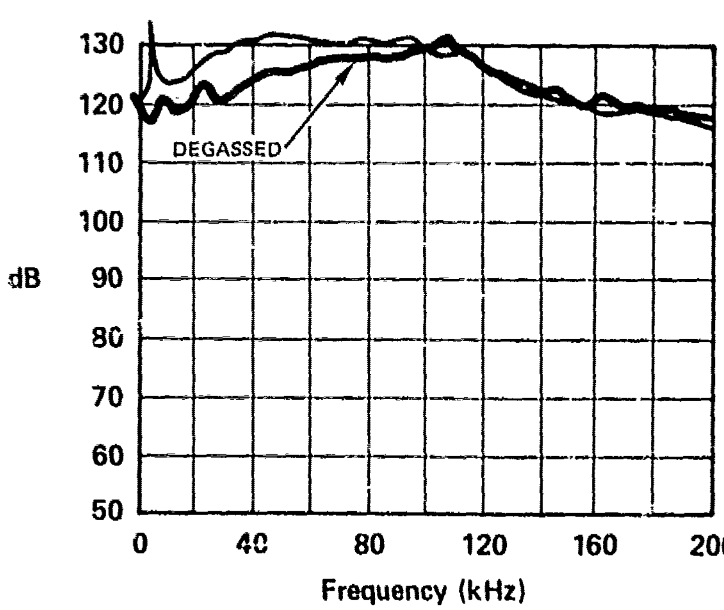
SANDERS SERVO VALVE NO. SV-438-10P
INLET – 1500 PSI
RETURN – 500 PSI
LOCATION – NUC SALTWATER TEST POOL



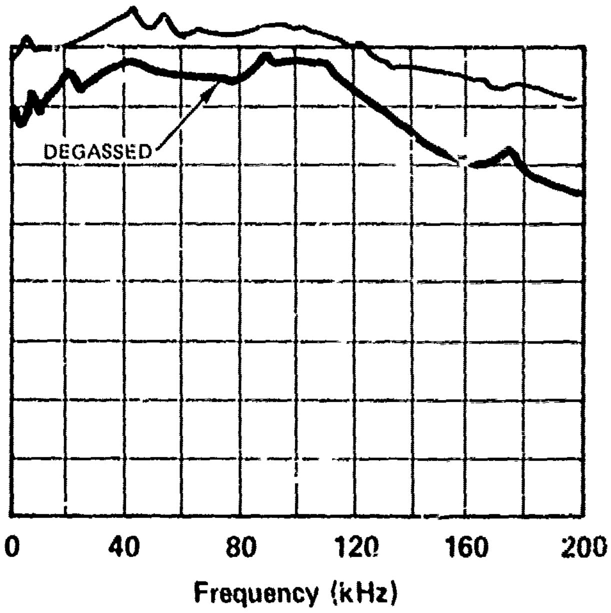
FLOW – 5 GPM
B-328



FLOW – 10 GPM
B-329



FLOW – 15 GPM
B-330



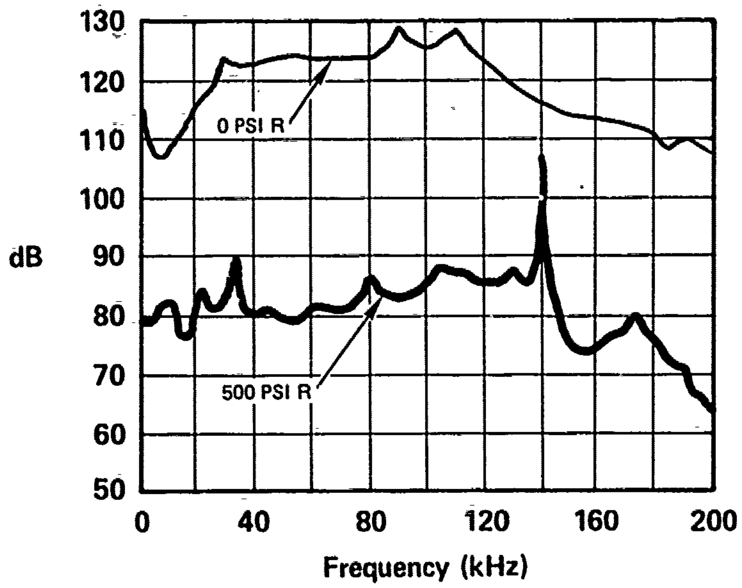
FLOW – 20 GPM
B-331

COMPARATIVE DATA (DEGASSING)

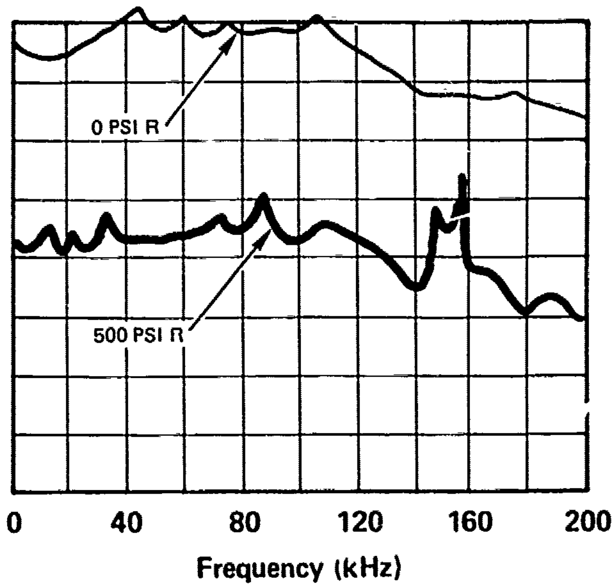
VICKERS RELIEF VALVE

DEGASSED OIL	vs	INLET – 1000 PSI
INLET – 1000 PSI		RETURN – 0 PSI
RETURN – 0 PSI		

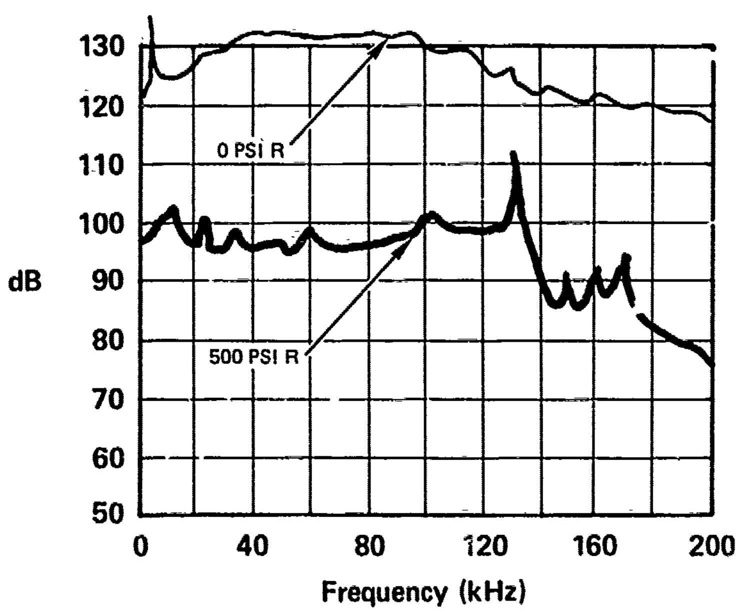
LOCATION – SALTWATER TEST POOL



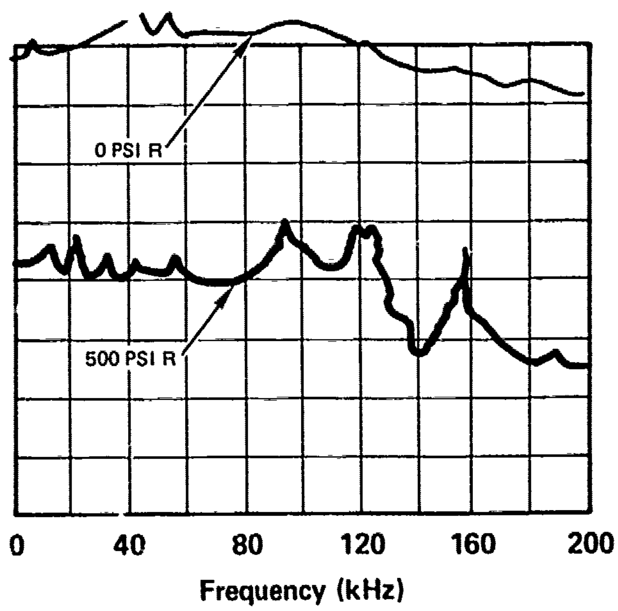
FLOW – 5 GPM
332



FLOW – 10 GPM
B-333



FLOW – 15 GPM
B-334



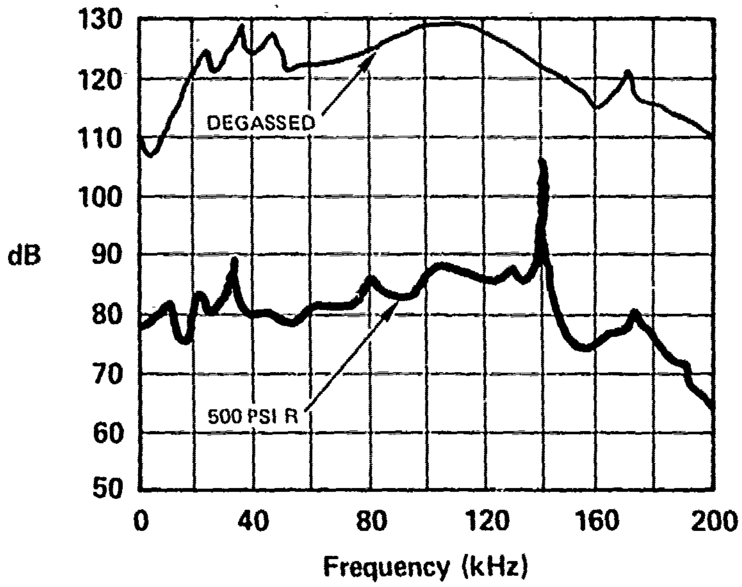
FLOW – 20 GPM
B-335

COMPARATIVE DATA (BACK-PRESSURING)

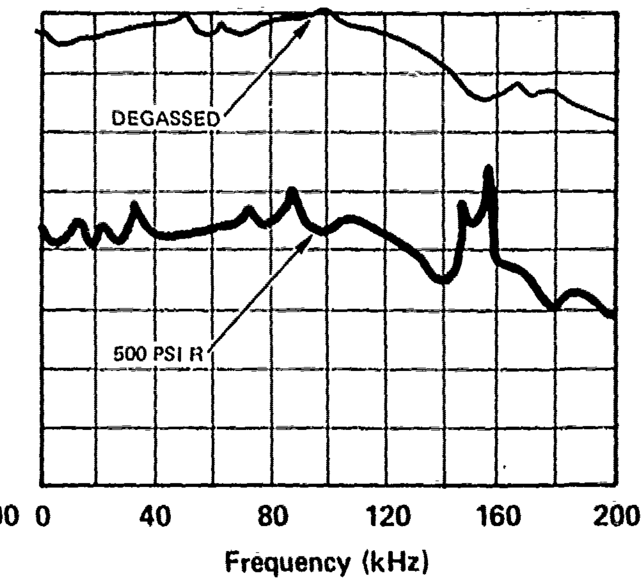
VICKERS RELIEF VALVE

INLET – 1000 PSI vs INLET – 1500 PSI
RETURN – 0 PSI RETURN – 500 PSI

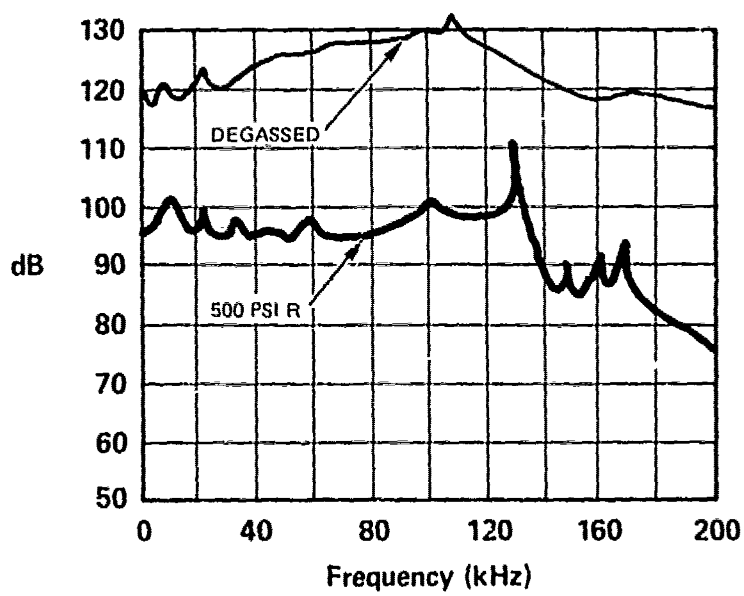
LOCATION – NUC SALTWATER TEST POOL



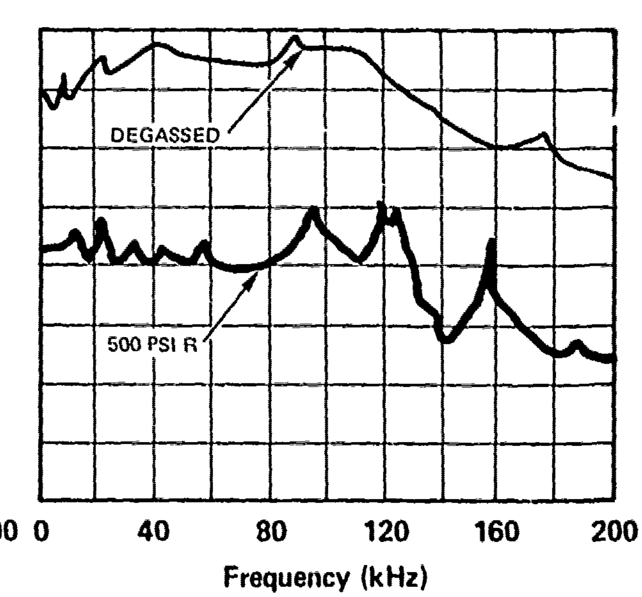
FLOW – 5 GPM
B-336



FLOW – 10 GPM
B-337



FLOW – 15 GPM
B-338

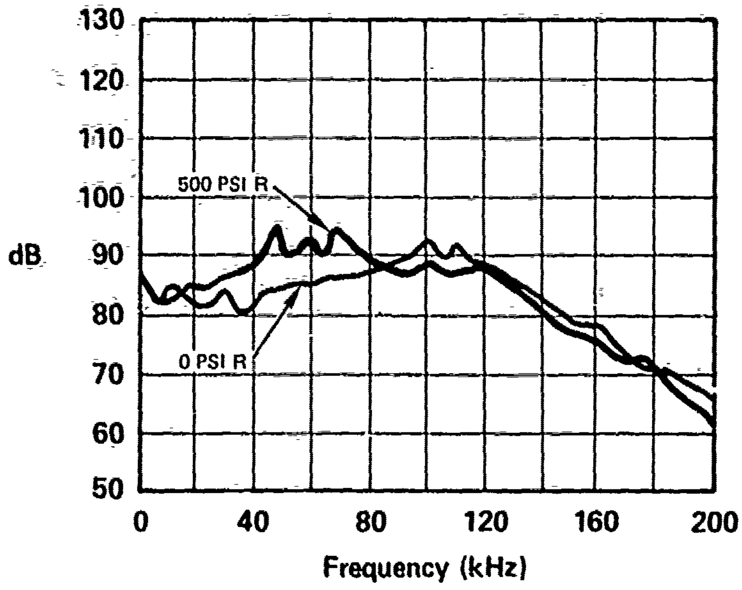


FLOW – 20 GPM
B-339

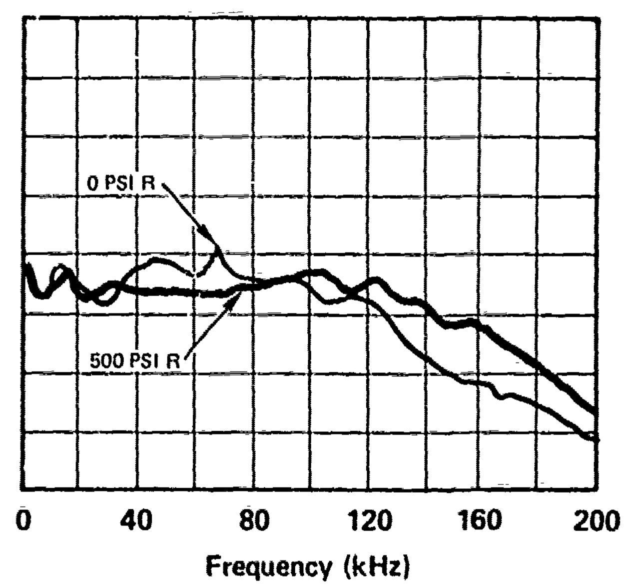
VICKERS RELIEF VALVE (DEGASSING vs BACK-PRESSURING)

DEGASSED OIL	vs	BACK-PRESSURED
INLET – 1000 PSI		INLET – 1500 PSI
RETURN – 0 PSI		RETURN – 500 PSI

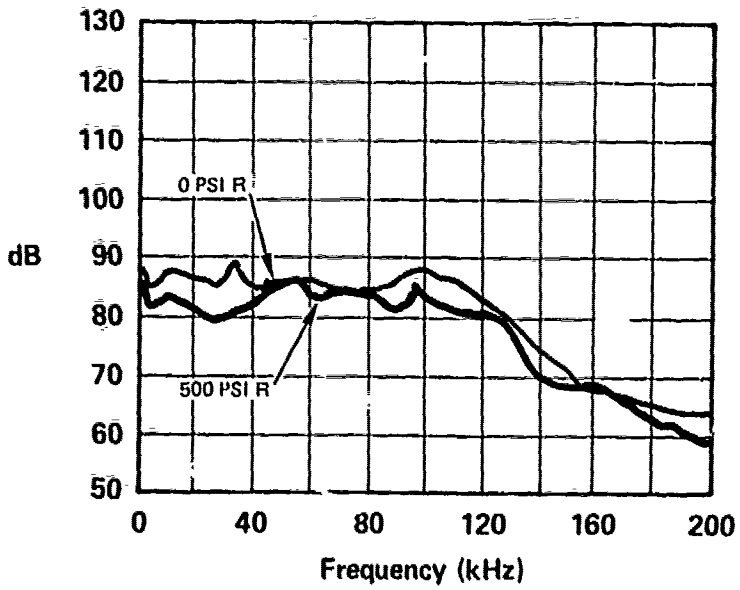
LOCATION – NUC SALTWATER TEST POOL



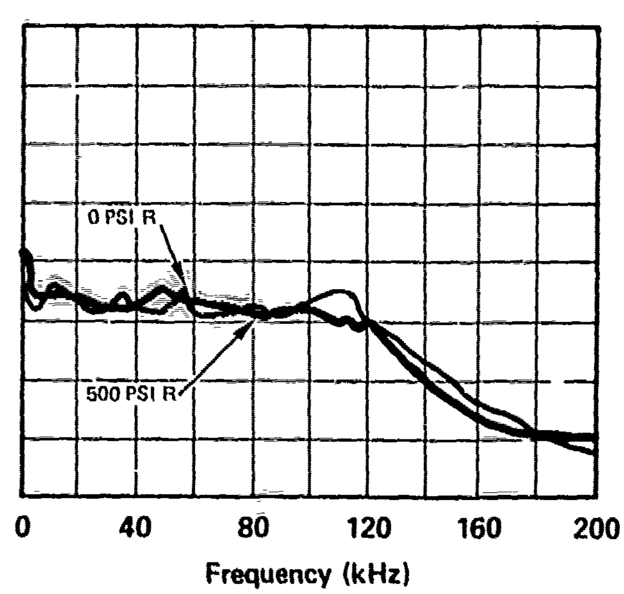
FLOW – 5 GPM
E-410



FLOW – 10 GPM
E-411



FLOW – 15 GPM
E-412

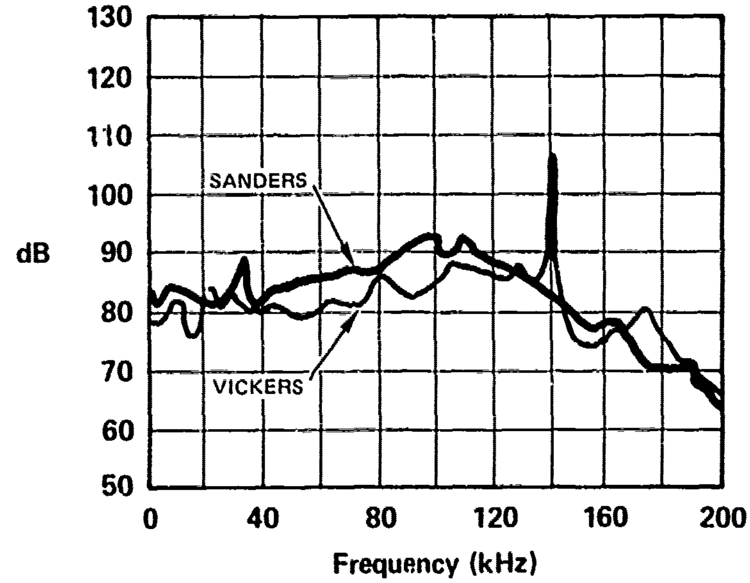


FLOW – 20 GPM
E-413

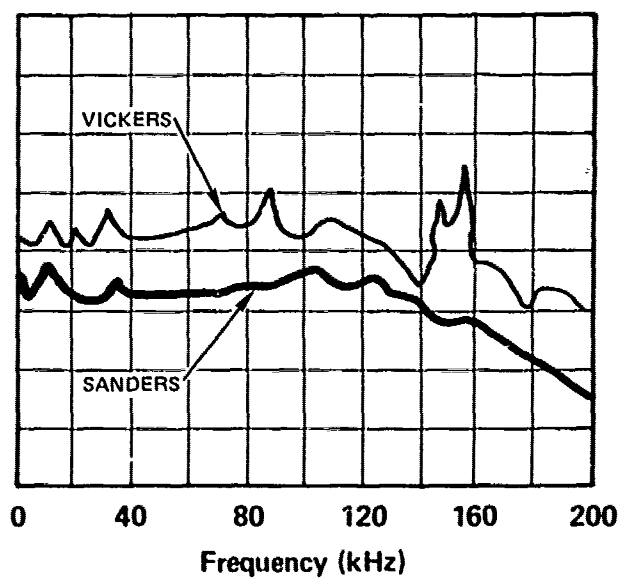
SANDERS SERVO VALVE NO. SV-438-10P (BACK-PRESSURING)

INLET – 1000 PSI RETURN – 0 PSI	vs	INLET – 1500 PSI RETURN – 500 PSI

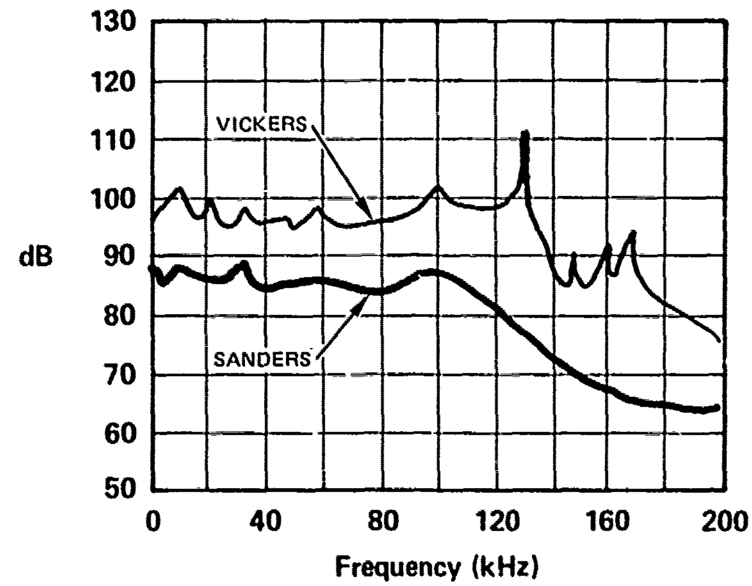
LOCATION – NUC SALTWATER TEST POOL



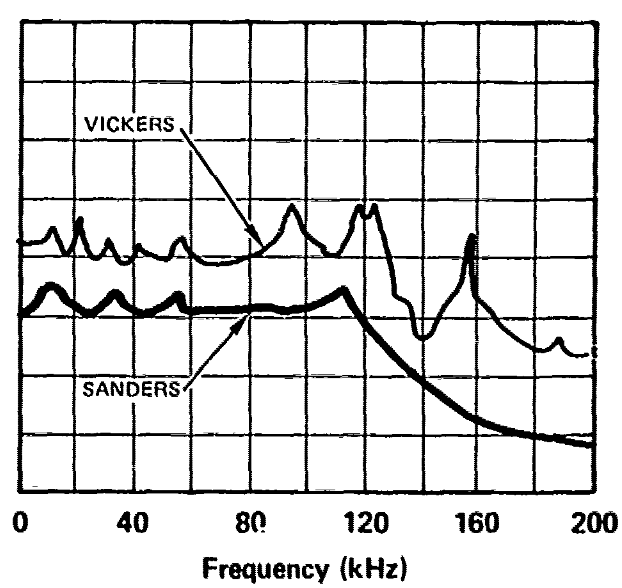
FLOW – 5 GPM
G-101



FLOW – 10 GPM
G-102



FLOW – 15 GPM
G-103

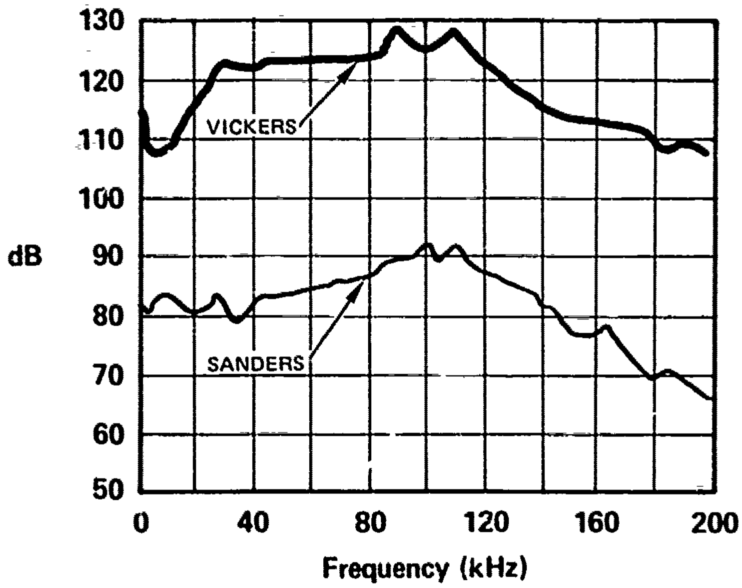


FLOW – 20 GPM
G-104

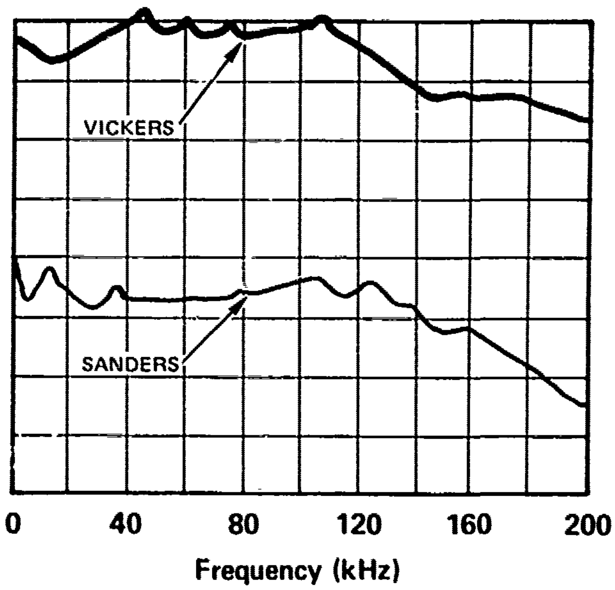
COMPARATIVE DATA (VICKERS vs SANDERS VALVES)

VICKERS	vs	SANDERS
INLET – 1500 PSI		INLET – 1000 PSI
RETURN – 500 PSI		RETURN – 0 PSI

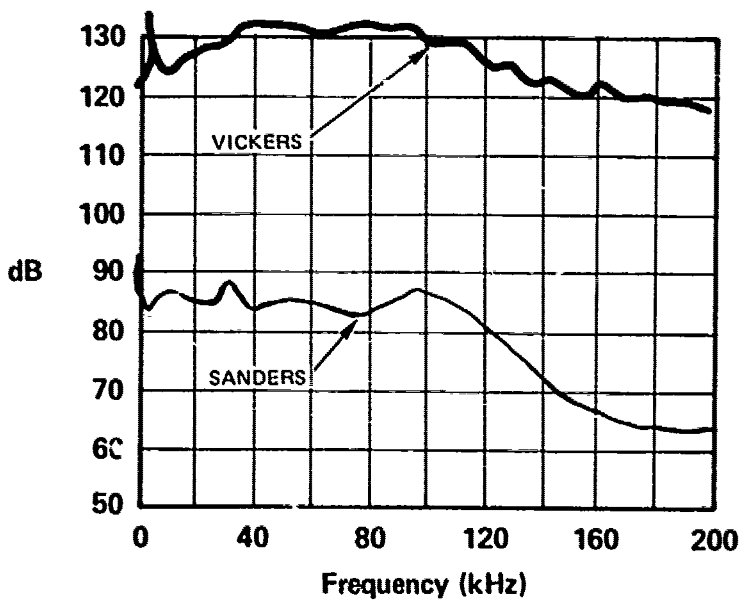
LOCATION – NUC SALTWATER TEST POOL



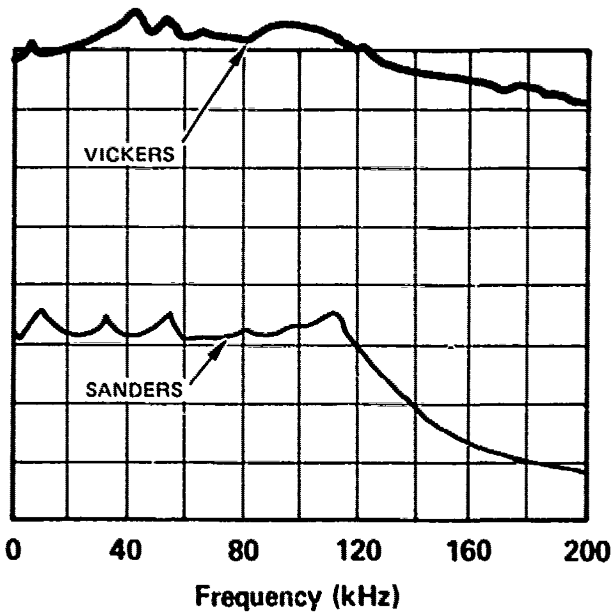
FLOW – 5 GPM
G-105



FLOW – 10 GPM
G-106



FLOW – 15 GPM
G-107



FLOW – 20 GPM
G-108

COMPARATIVE DATA (VICKERS vs SANDERS VALVES)

INLET – 1000 PSI
RETURN – 0 PSI

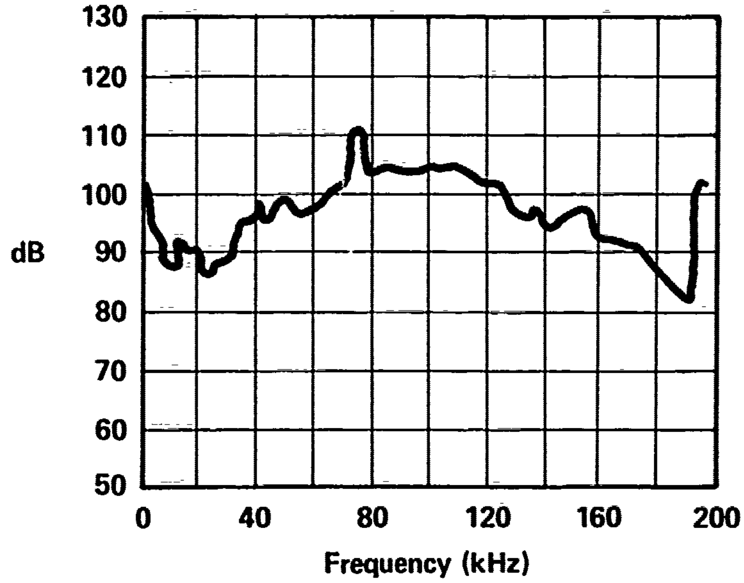
LOCATION – NUC SALTWATER TEST POOL

APPENDIX C

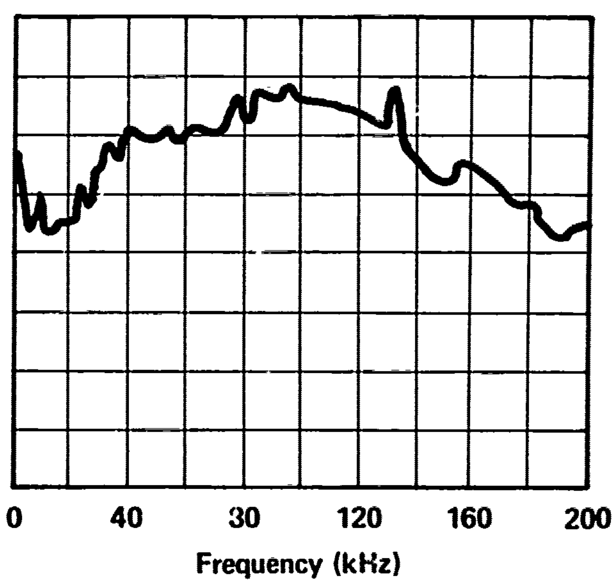
TEST DATA OF THIRD TEST SERIES

GRAPHS

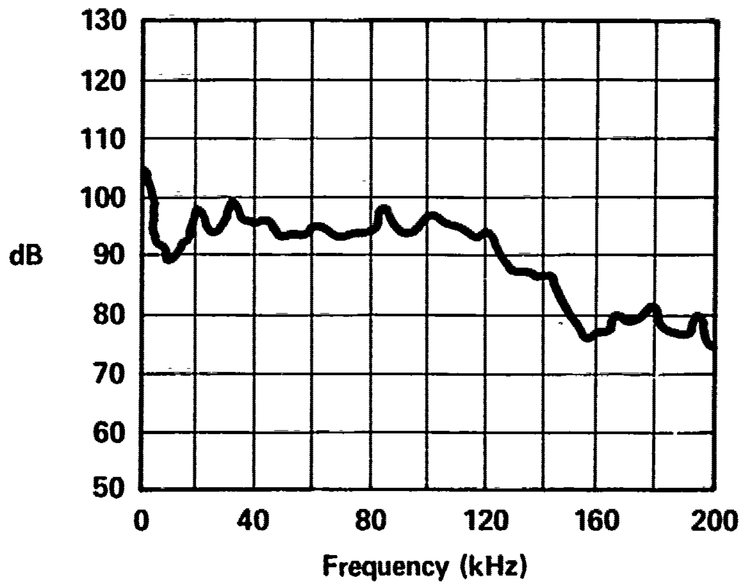
This appendix presents the results of the third series of acoustic tests, depicted by noise profile graphs for each of the components and specified test conditions. The decibel scales for all graphs have a reference of 1 microPascal per hertz per yard (dB//μPa/Hz/yd).



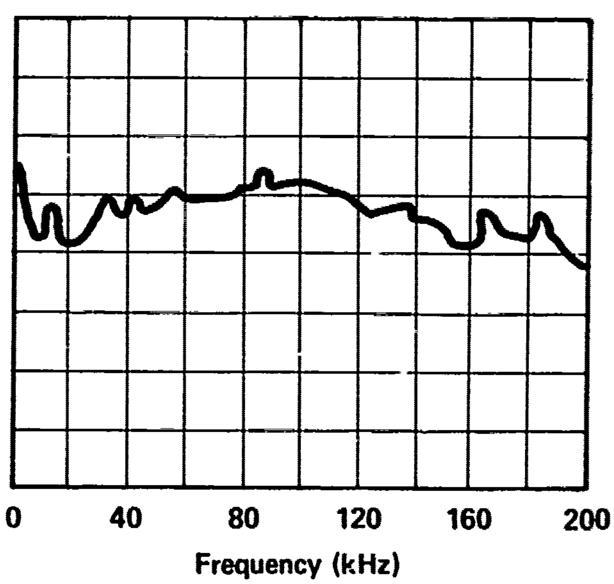
FLOW – 5 GPM
B-601



FLOW – 10 GPM
B-602



FLOW – 15 GPM
B-603

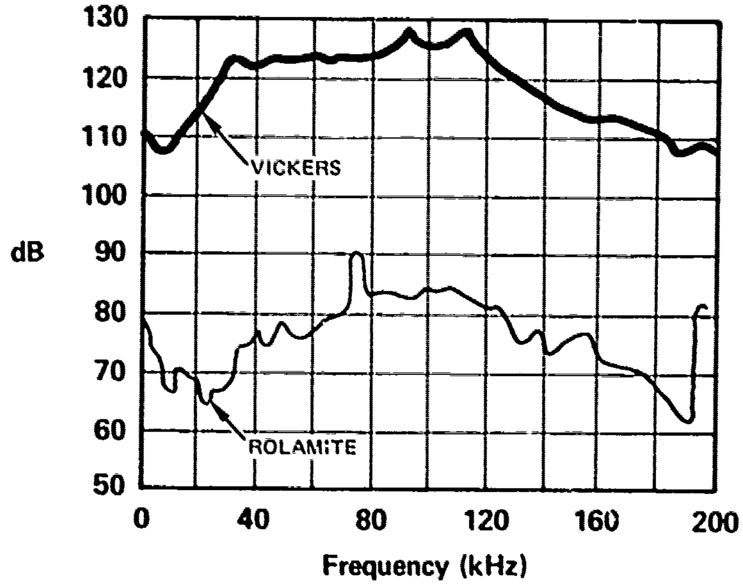


FLOW – 20 GPM
B-604

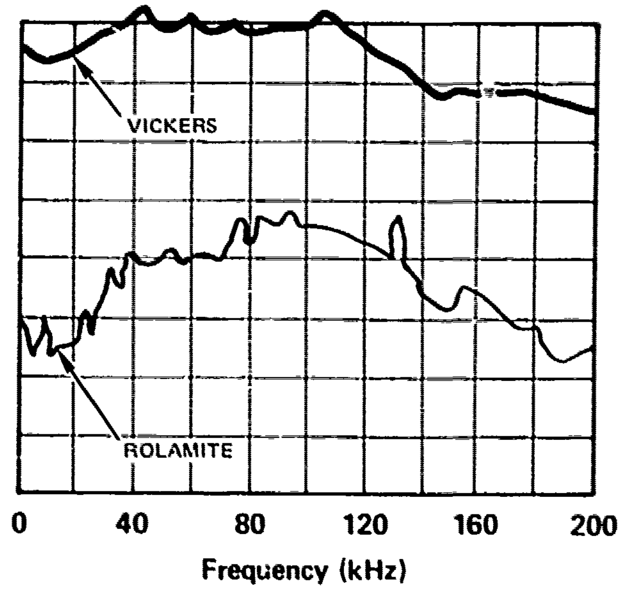
ROLAMITE PRESSURE RELIEF VALVE (EXTERNAL PILOT VALVE)

INLET – 1000 PSI
RETURN – 0 PSI

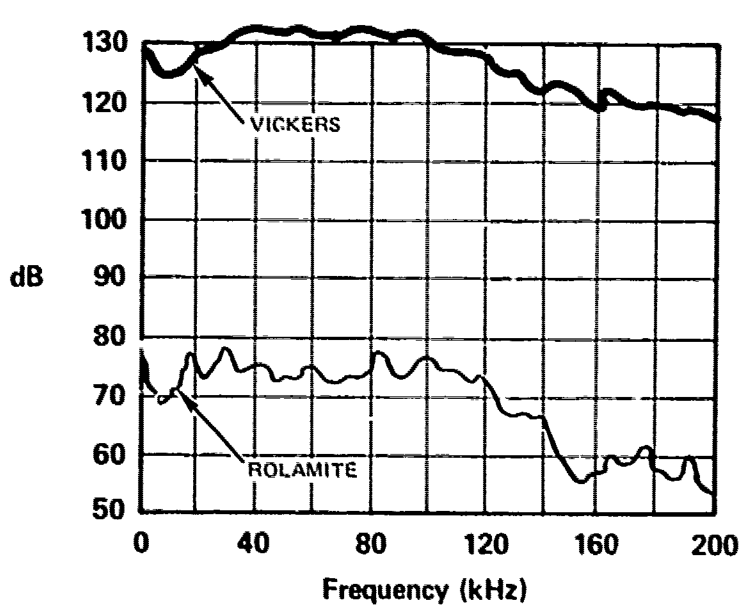
LOCATION – NUC SALTWATER TEST POOL



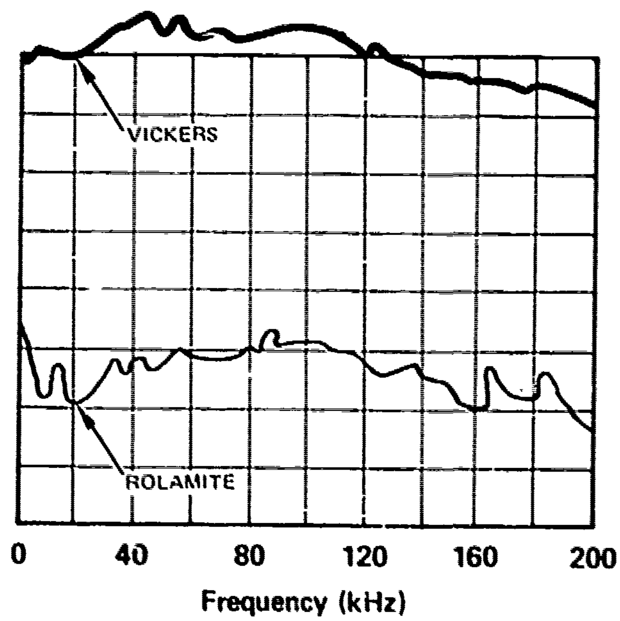
FLOW – 5 GPM
G-201



FLOW – 10 GPM
G-202



FLOW – 15 GPM
G-203

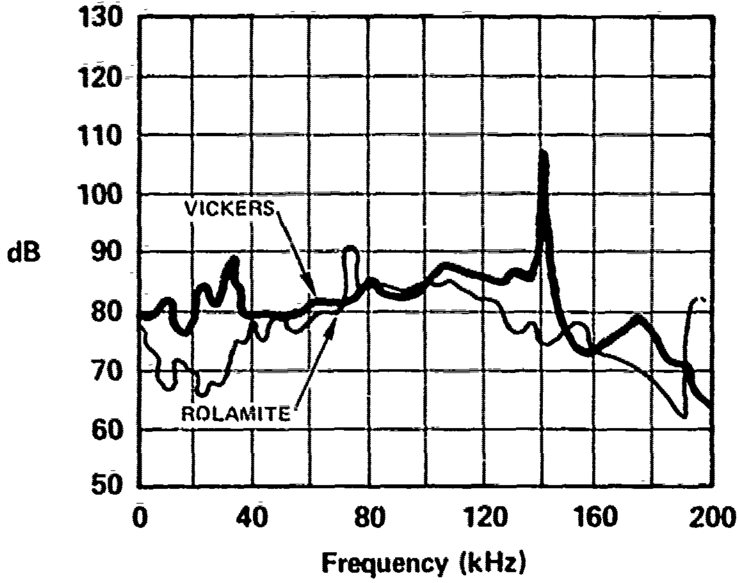


FLOW – 20 GPM
G-204

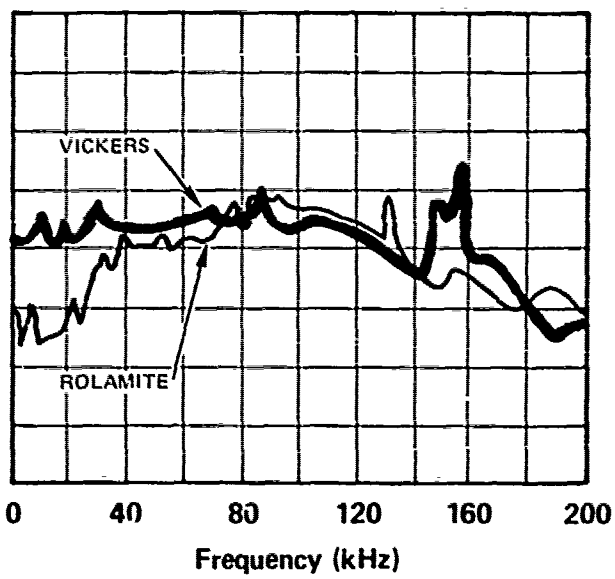
COMPARATIVE DATA (ROLAMITE vs. VICKERS)

INLET – 1000 PSI
RETURN – 0 PSI

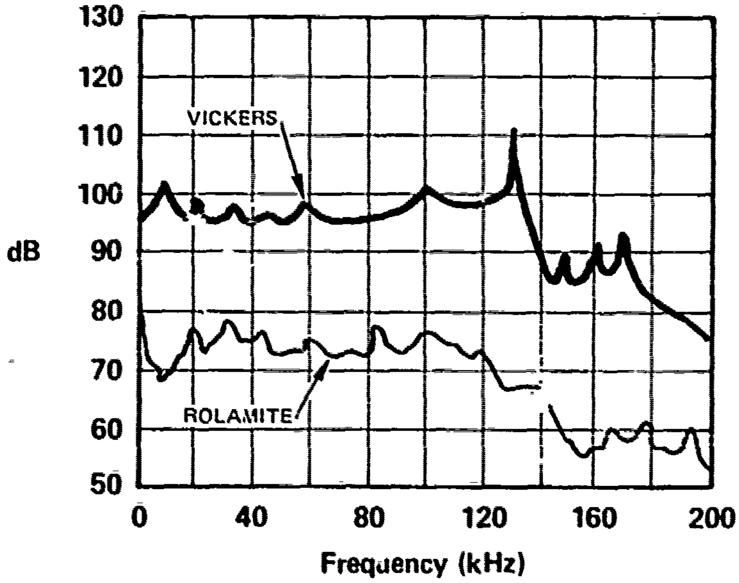
LOCATION – NUC SALTWATER TEST POOL



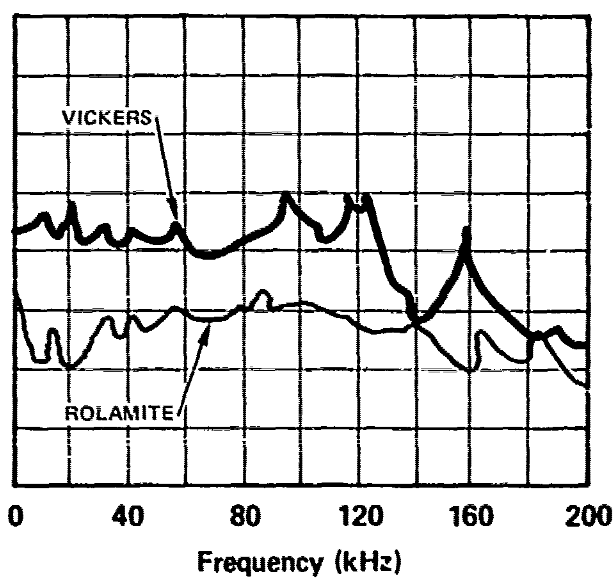
FLOW – 5 GPM
G-205



FLOW – 10 GPM
G-206



FLOW – 15 GPM
G-207

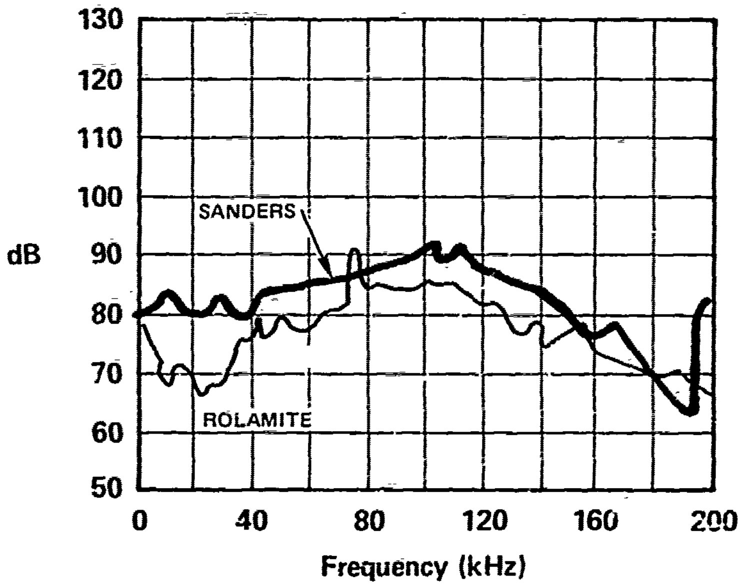


FLOW – 20 GPM
G-208

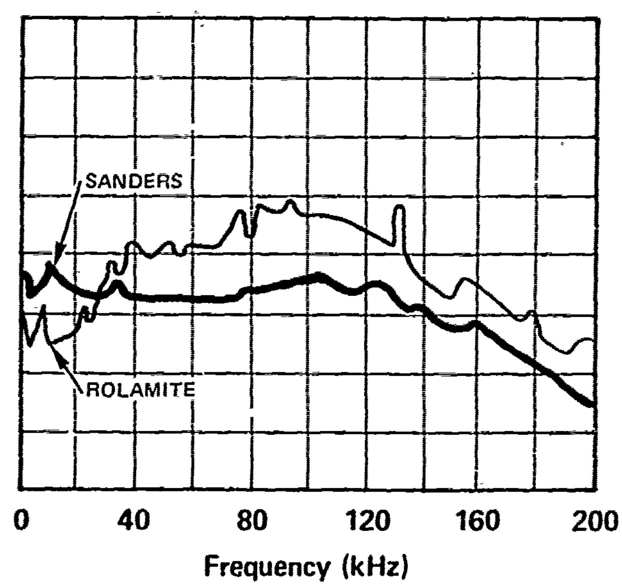
COMPARATIVE DATA (ROLAMITE vs VICKERS)

	ROLAMITE	VICKERS
INLET	1000 PSI	1500 PSI
RETURN	0 PSI	500 PSI

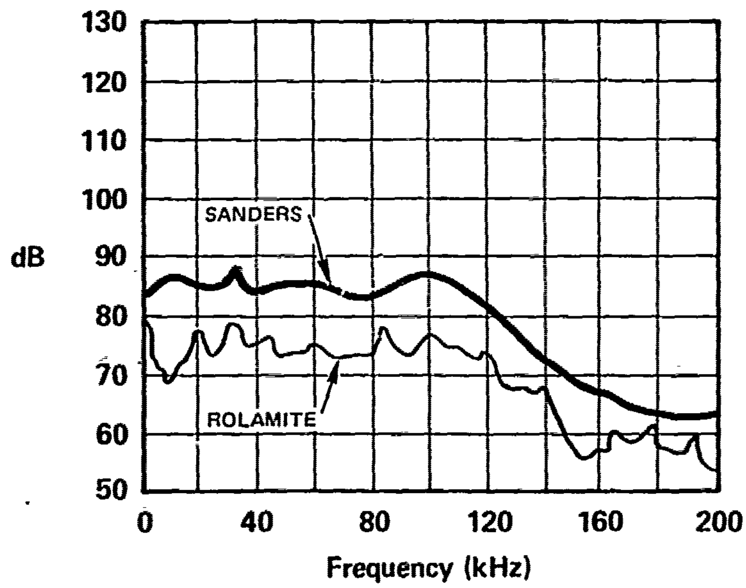
LOCATION – NUC SALTWATER TEST POOL



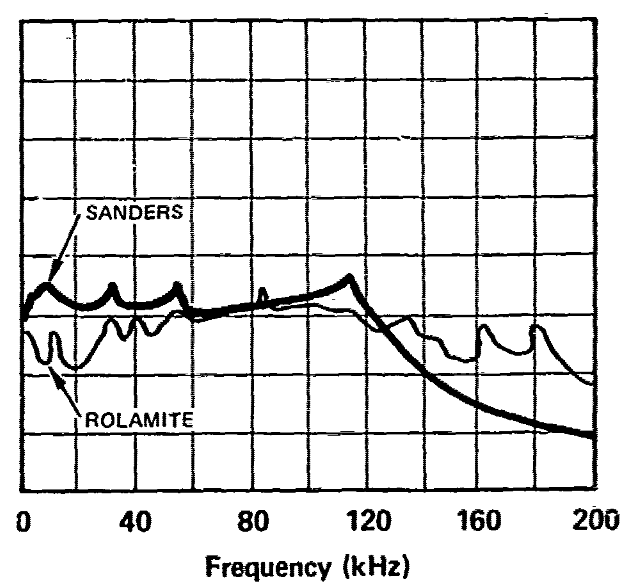
FLOW – 5 GPM
G-301



FLOW – 10 GPM
G-302



FLOW – 15 GPM
G-303

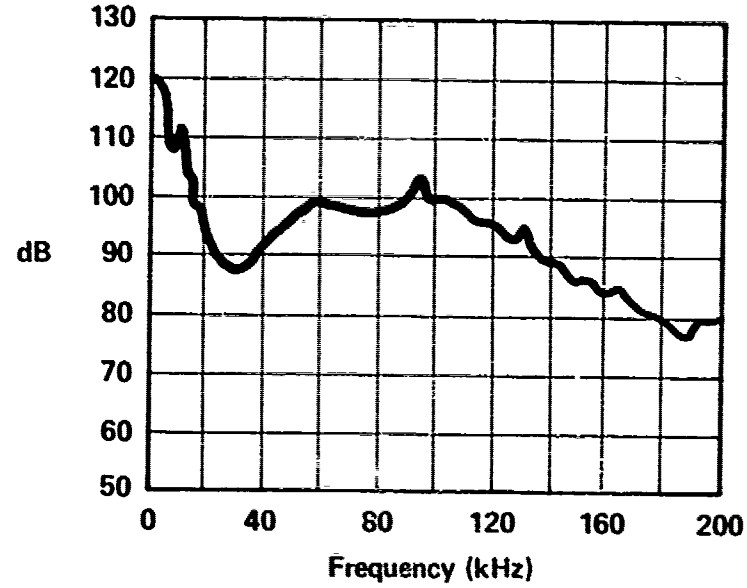


FLOW – 20 GPM
G-304

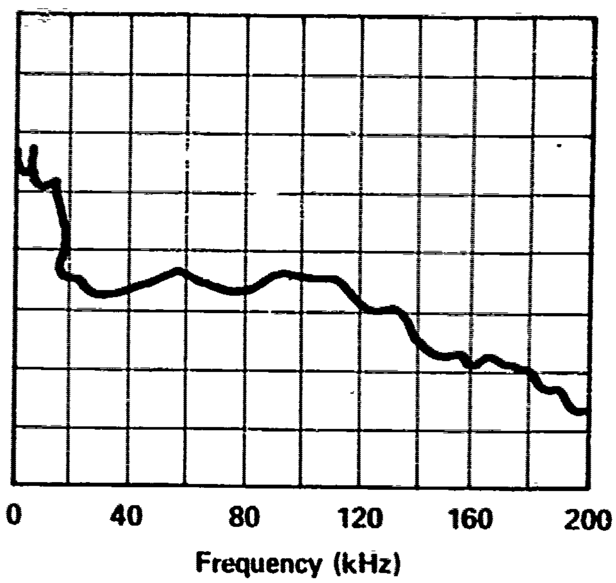
COMPARATIVE DATA (ROLAMITE vs SANDERS)

INLET – 1000 PSI
RETURN – 0 PSI

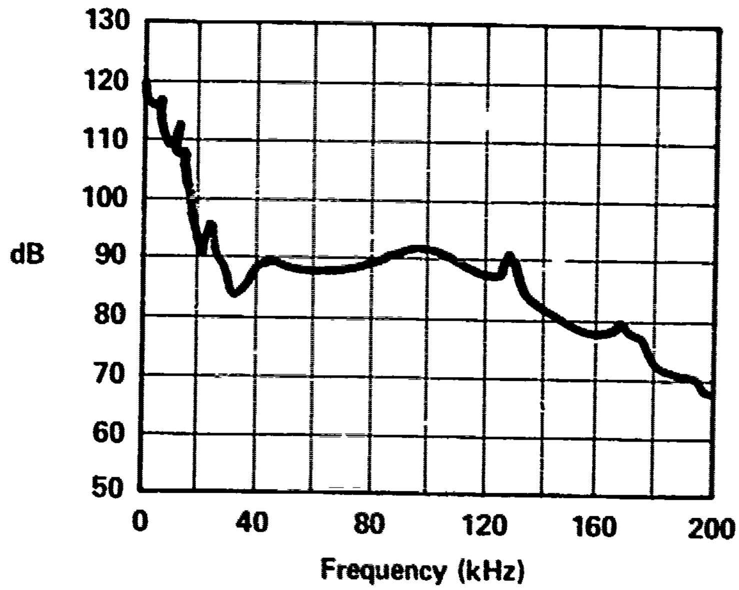
LOCATION – NUC SALTWATER TEST POOL



OUTPUT
PRESSURE – 0 PSI
D-501



OUTPUT
PRESSURE – 500 PSI
D-502

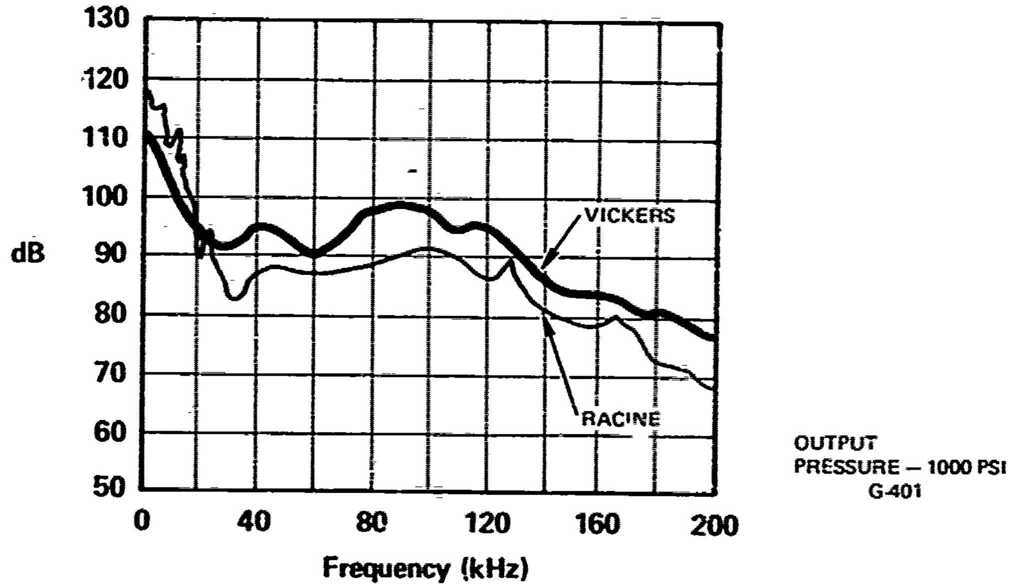


OUTPUT
PRESSURE – 1000 PSI
D-503

HYDRASTAR PUMP

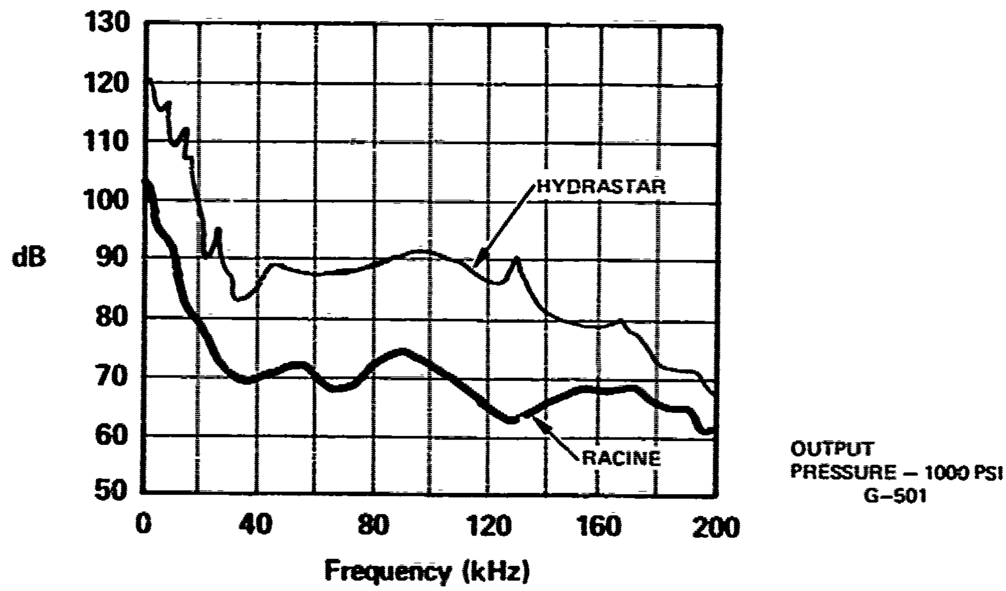
RPM – 1750
FLOW – 20 GPM

LOCATION – NUC SALTWATER TEST POOL



COMPARATIVE DATA (HYDRASTAR vs VICKERS PUMPS)
PUMP PRESS – 1000 PSI

HYDRASTAR	VICKERS
RPM – 1750	RPM – 1750
FLOW – 20 GPM	FLOW – 20 GPM



COMPARATIVE DATA (HYDRASTAR vs RACINE SUPERVANE PUMPS)
PUMP PRESS – 1000 PSI

HYDRASTAR	RACINE
RPM – 1750	RPM – 1750
FLOW – 20 GPM	FLOW – 13 GPM

APPENDIX D

NOSC ROLAMITE VALVE DESIGN

A Rolamite valve was designed and tested by the Naval Ocean Systems Center, Hawaii Laboratory. The valve is shown in figures D-1 and D-2; design details are contained in the NOSC drawing DRS-1000 (3 sheets).

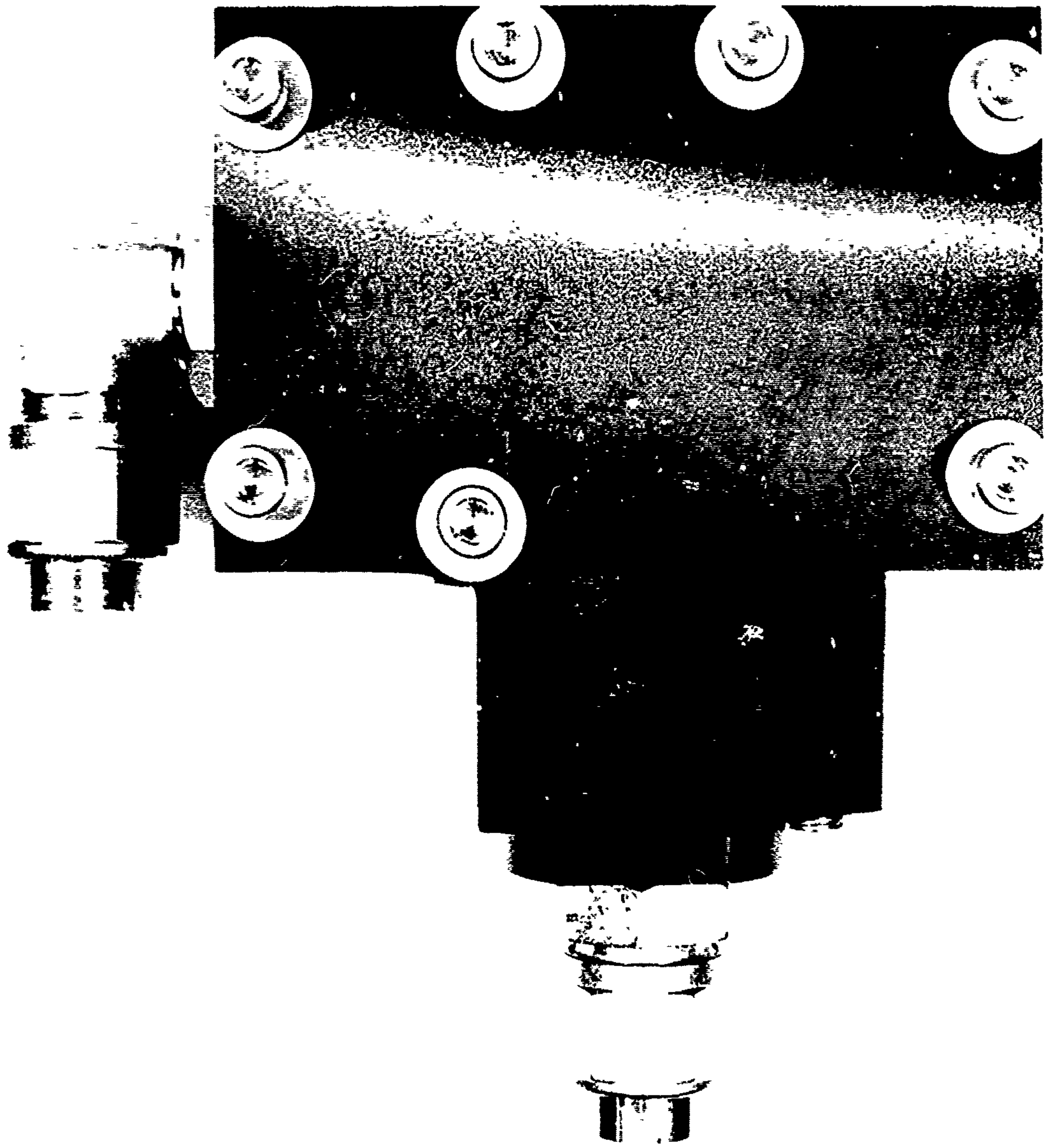


Figure D-1. NOSC Rolamite valve

"Quiet throttling" is achieved through use of a porous port made of Brunswick Number 8 Collimated Hole Structure (CHS) material. The Number 8 CHS is a 50 percent open area structure containing about 11,500 holes having an equivalent hole diameter (based on area measurement) of about .009 inch. The material is type 304 stainless steel.

Two CHS disks are used in series separated by a plenum chamber. The first disk (part number 10) is 0.060 inches thick. The second disk (part number 12) is 0.200 inches thick.

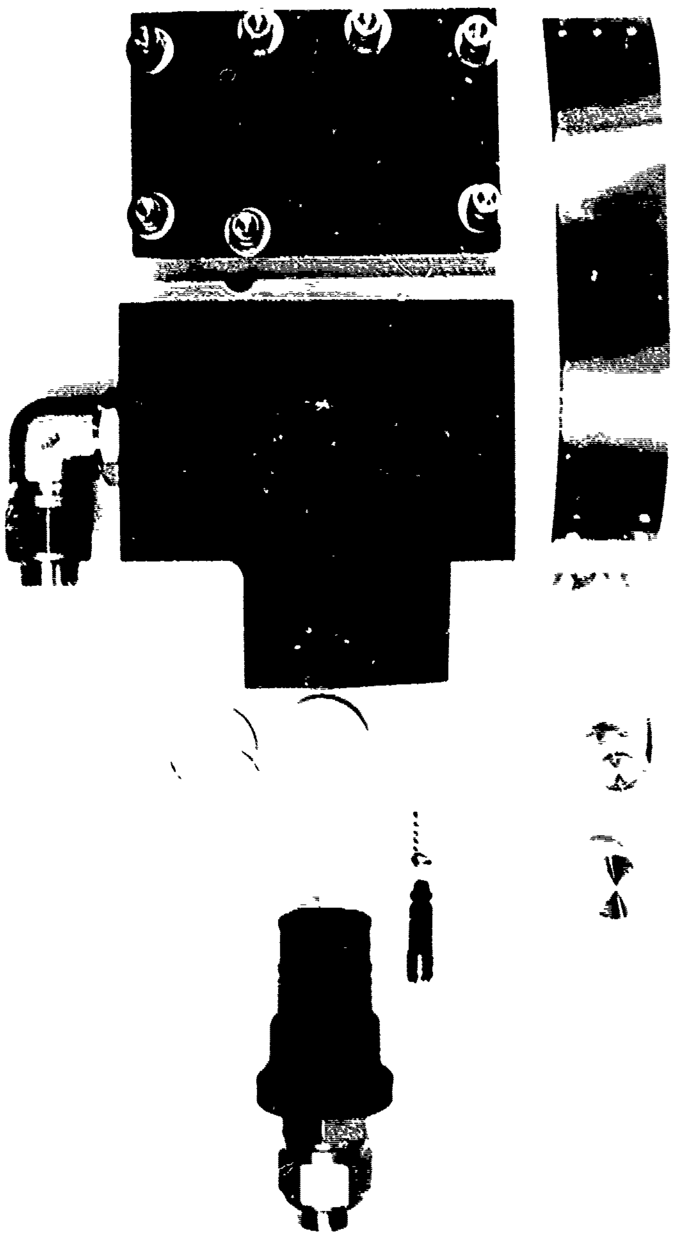
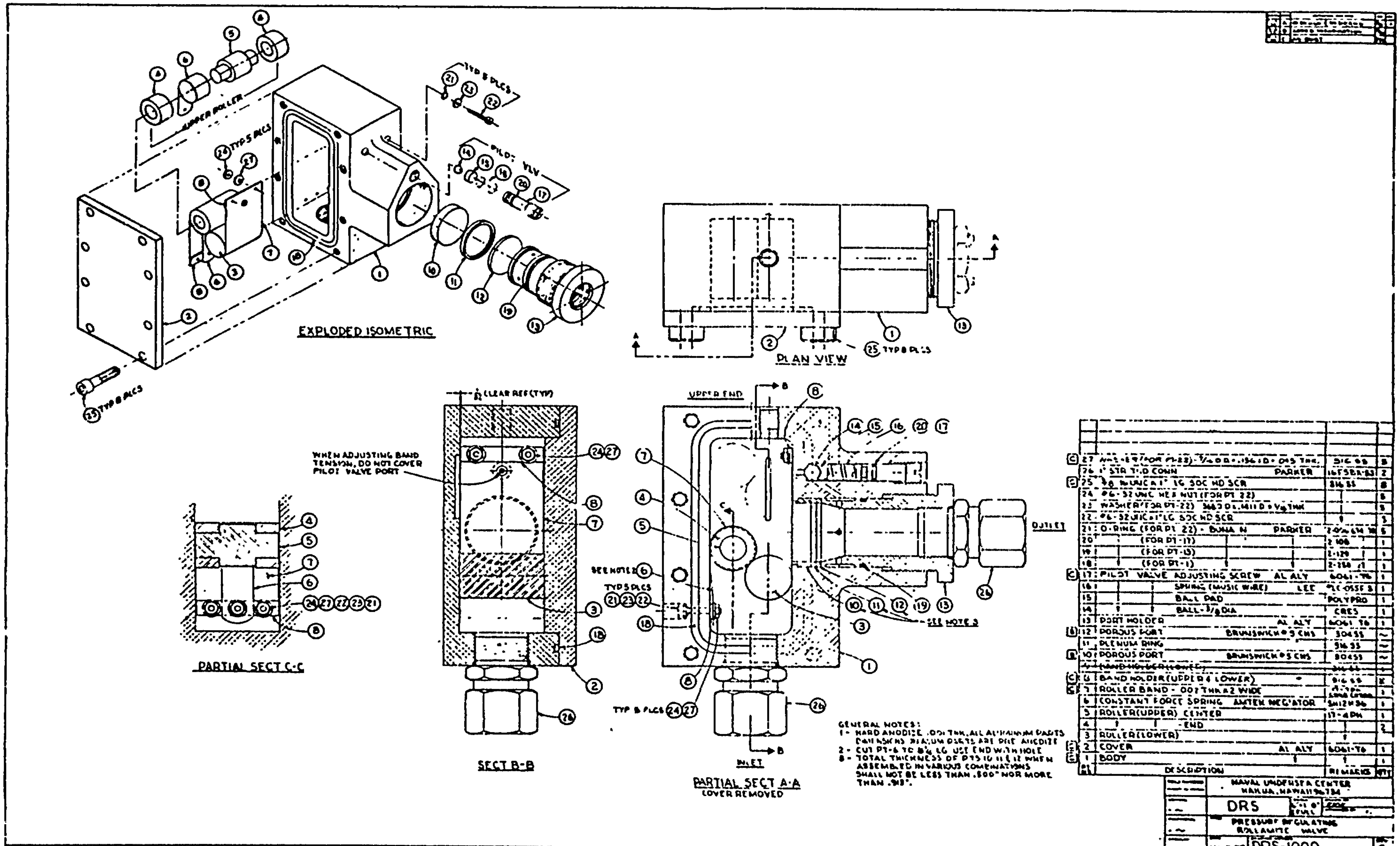
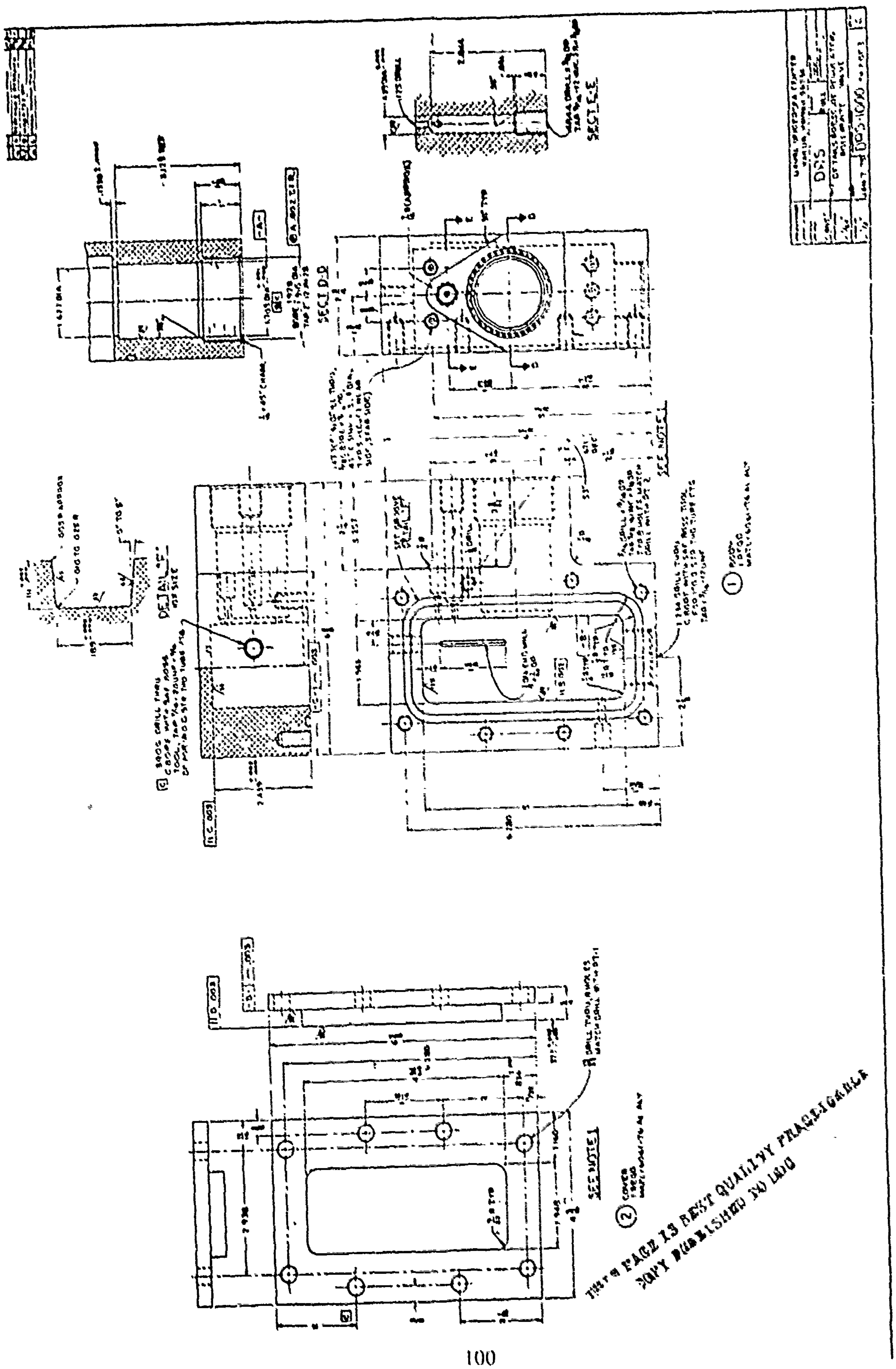
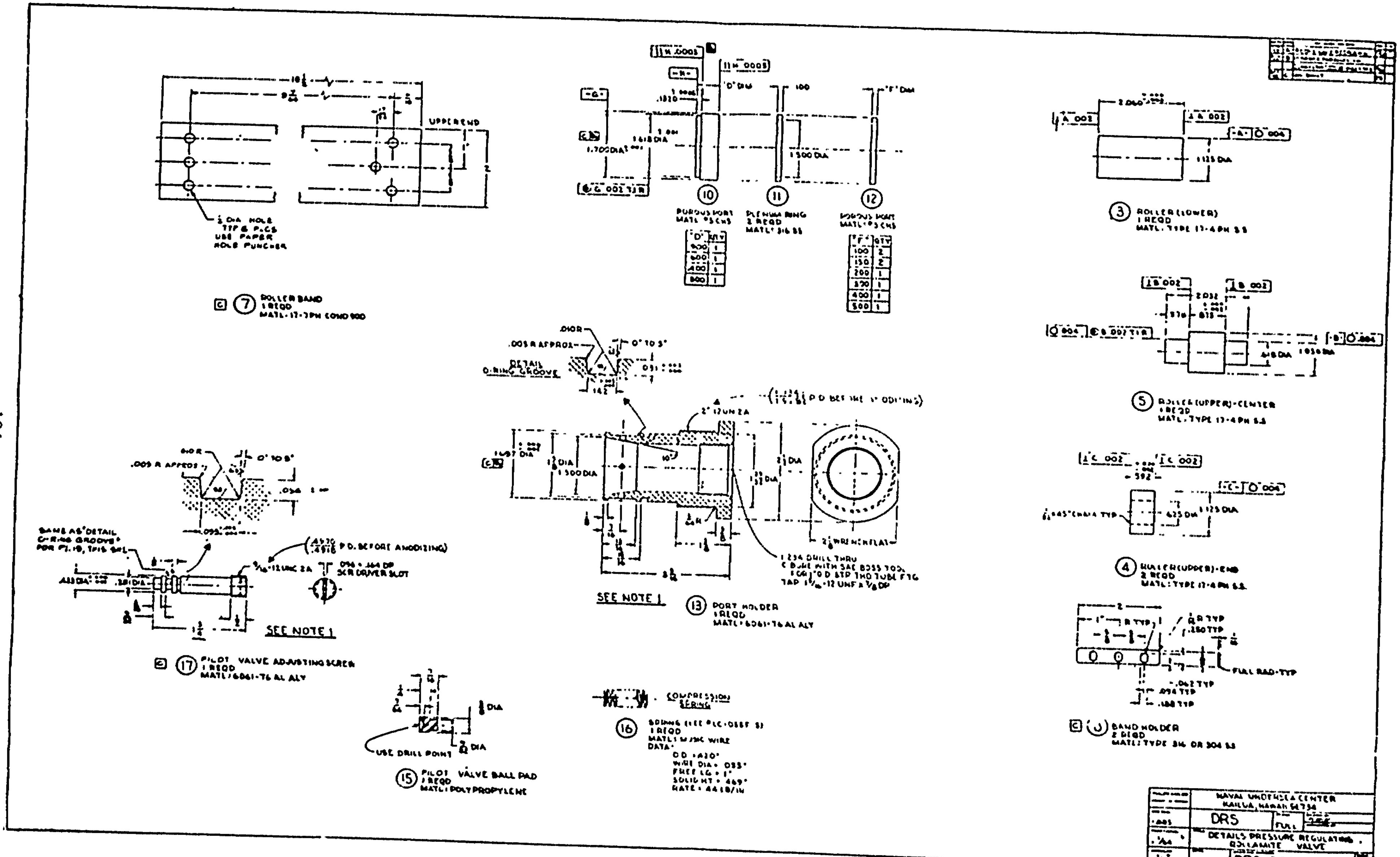


Figure D-2. NOSC Rotamite valve parts.



THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC




ROLLER BAND
1 REQD
MATL: 17-7PH COND 900
POROUS PORT
PLENUM RING
2 REQD
MATL: 316 SS
POROUS PORT
ROLLER (LOWER)
1 REQD
MATL: TYPE 17-4PH SS
ROLLER (UPPER)-CENTER
MATL: TYPE 17-4PH SS
ROLLER (UPPER)-END
2 REQD
MATL: TYPE 17-4PH SS
DETAIL
O-RING GROOVE
SEE NOTE 1
PORT HOLDER
1 REQD
MATL: 6061-T6 AL ALY
PILOT VALVE ADJUSTING SCREW
1 REQD
MATL: 6061-T6 AL ALY
SEE NOTE 1
COMPRESSION SPRING
MATL: MUSIC WIRE
USE DRILL POINT
PILOT VALVE BALL PAD
1 REQD
MATL: POLYPROPYLENE
BAND HOLDER
2 REQD
MATL: TYPE 316 OR 304 SS
FULL RAD-TYP
NAVAL UNDERSEA CENTER
DRS
FULL
DETAILS PRESSURE REGULATING ROLLAMITE VALVE
DRS-1000